# ATSC Standard:
# Physical Layer Protocol

Doc. A/322:2022-03
31 March 2022

**Advanced Television Systems Committee**
1300 I Street, N.W., Suite 400E
Washington, D.C. 20005
202-872-9160

The Advanced Television Systems Committee, Inc. is an international, non-profit organization developing voluntary standards and recommended practices for broadcast television and multimedia data distribution. ATSC member organizations represent the broadcast, professional equipment, motion picture, consumer electronics, computer, cable, satellite, and semiconductor industries. ATSC also develops implementation strategies and supports educational activities on ATSC standards. ATSC was formed in 1983 by the member organizations of the Joint Committee on Inter-society Coordination (JCIC): the Consumer Technology Association (CTA), the Institute of Electrical and Electronics Engineers (IEEE), the National Association of Broadcasters (NAB), the Internet & Television Association (NCTA), and the Society of Motion Picture and Television Engineers (SMPTE). For more information visit www.atsc.org.

---

*Note*: The user's attention is called to the possibility that compliance with this standard may require use of an invention covered by patent rights. By publication of this standard, no position is taken with respect to the validity of this claim or of any patent rights in connection therewith. One or more patent holders have, however, filed a statement regarding the terms on which such patent holder(s) may be willing to grant a license under these rights to individuals or entities desiring to obtain such a license. Details may be obtained from the ATSC Secretary and the patent holder.

---

Implementers with feedback, comments, or potential bug reports relating to this document may contact ATSC at https://www.atsc.org/feedback/.

## Disclaimer

Not all optional settings that are combinations with non-optional settings have been tested at the time of release of this document.

## Revision History

| Version | Date |
|---|---|
| A/322:2016 approved | 7 September 2016 |
| A/322:2017 approved<br>Amendment No. 1 to A/322:2017 approved as a roll-up | 9 February 2017<br>6 June 2017 |
| A/322:2018 approved | 26 December 2018 |
| A/322:2020 approved | 23 January 2020 |
| A/322:2021 approved | 20 January 2021 |
| A/322:2022-03 published (references to ATSC documents updated) | 31 March 2022 |

# Table of Contents


1. SCOPE ..... 1
   1.1 Introduction and Background 1
   1.2 Organization 1
2. REFERENCES ..... 2
   2.1 Normative References 2
   2.2 Informative References 2
3. DEFINITION OF TERMS ..... 2
   3.1 Compliance Notation 2
   3.2 Treatment of Syntactic Elements 3
      3.2.1 Reserved Elements 3
   3.3 Acronyms, Abbreviations and Mathematical Operators 3
   3.4 Terms 5
4. SYSTEM OVERVIEW ..... 6
   4.1 Features 6
   4.2 System Architecture 7
   4.3 Central Concepts 10
5. INPUT FORMATTING ..... 10
   5.1 Encapsulation and Compression 11
      5.1.1 Number of PLPs 11
   5.2 Baseband Formatting 11
      5.2.1 Mapping ALP Packets to Baseband Packets 12
      5.2.2 Baseband Packet Header 13
      5.2.3 Scrambling of Baseband Packets 16
6. BIT-INTERLEAVED CODED MODULATION (BICM) ..... 17
   6.1 Forward Error Correction (FEC) 17
      6.1.1 FEC Frame Structure 17
      6.1.2 Outer Encoding 19
      6.1.3 Inner Encoding 21
   6.2 Bit Interleavers 24
      6.2.1 Parity Interleaver 24
      6.2.2 Group-Wise Interleaver 24
      6.2.3 Block Interleavers 25
   6.3 Constellation Mapping 29
      6.3.1 Constellation Overview 30
      6.3.2 Modulation and Coding Combinations 30
      6.3.3 Demultiplexing Operation 31
      6.3.4 Bit to IQ Mapping 32
   6.4 Layered Division Multiplexing (LDM) 34
      6.4.1 LDM Encoding 34
      6.4.2 Injection Level Controller 36
      6.4.3 Power Normalizer 36
      6.4.4 LDM Example 37
   6.5 Protection for L1 Signaling 38
      6.5.1 Overview 38

6.5.2 Common Blocks for L1-Basic and L1-Detail 39
6.5.3 L1-Detail Specific Block Details 50
7. FRAMING AND INTERLEAVING 55
7.1 Time Interleaving 55
7.1.1 Time Interleaver Modes 55
7.1.2 Time Interleaver Size 56
7.1.3 Extended Interleaving 56
7.1.4 Convolutional Time Interleaver (CTI) Mode 57
7.1.5 Hybrid Time Interleaver (HTI) Mode 58
7.2 Framing 67
7.2.1 Overview 67
7.2.2 Frame Structure 67
7.2.3 Number of Carriers 69
7.2.4 Frame Symbol Types 69
7.2.5 Preamble 70
7.2.6 Cell Multiplexing 72
7.2.7 PLP Multiplexing Approaches within a Subframe 81
7.3 Frequency Interleaving 90
8. WAVEFORM GENERATION 94
8.1 Pilot Insertion 95
8.1.1 Introduction 95
8.1.2 Reference Sequence 95
8.1.3 Scattered Pilot Insertion 96
8.1.4 Continual Pilot Insertion 97
8.1.5 Edge Pilot Insertion 99
8.1.6 Preamble Pilot Insertion 99
8.1.7 Subframe Boundary Pilot Insertion 101
8.2 MISO 101
8.2.1 Transmit Diversity Code Filter Sets 101
8.3 Inverse Fast Fourier Transform (IFFT) 102
8.4 Peak to Average Power Ratio Reduction Techniques 105
8.4.1 Tone Reservation 105
8.4.2 Active Constellation Extension (ACE) 106
8.5 Guard Interval 106
8.5.1 Guard Interval Extension for Time-aligned Frames 106
8.6 Bootstrap 108
9. L1 SIGNALING 108
9.1 Bootstrap 108
9.1.1 Versioning 108
9.1.2 Bootstrap Symbol 1 108
9.1.3 Bootstrap Symbol 2 109
9.1.4 Bootstrap Symbol 3 109
9.2 Syntax for L1-Basic Data 109
9.2.1 L1-Basic System and Frame Parameters 110
9.2.2 L1-Basic Parameters for L1-Detail 112
9.2.3 L1-Basic Parameters for First Subframe 113

9.2.4 L1-Basic Miscellaneous Parameters 114
9.3 Syntax and Semantics for L1-Detail Data 115
9.3.1 L1-Detail Miscellaneous Parameters 117
9.3.2 L1-Detail Channel Bonding Parameters (Frame) 118
9.3.3 L1-Detail Subframe Parameters 119
9.3.4 L1-Detail PLP Parameters 122
9.3.5 L1-Detail LDM Parameters 125
9.3.6 L1-Detail Channel Bonding Parameters (PLP) 125
9.3.7 L1-Detail MIMO Parameters (PLP) 126
9.3.8 L1-Detail Cell Multiplexing Parameters 126
9.3.9 L1-Detail Time Interleaver (TI) Parameters 127
*ANNEX A* : LDPC CODES ....130
A.1 LDPC Code Matrices ($N_{inner}$ = 64800) 130
A.2 LDPC Code Matrices ($N_{inner}$ = 16200) 142
*ANNEX B* : BIT INTERLEAVER SEQUENCES ....147
B.1 Permutation sequences of group-wise interleaving for $N_{inner}$ = 64800 ($N_{group}$ = 180) 147
B.2 Permutation sequences of group-wise interleaving for $N_{inner}$ = 16200 ($N_{group}$ = 45) 160
*ANNEX C* : CONSTELLATION DEFINITIONS AND FIGURES ....164
C.1 Constellation Definitions 164
C.2 Constellation Figures 171
C.3 Constellation Labeling 175
*ANNEX D* : CONTINUAL PILOT (CP) PATTERNS....178
D.1 Reference and Additional CP Indices 178
*ANNEX E* : SCATTERED PILOT (SP) PATTERNS ....182
E.1 SISO Scattered Pilot Patterns 182
*ANNEX F* : NUMBER OF ACTIVE DATA CELLS IN SUBFRAME BOUNDARY SYMBOL ....187
F.1 Subframe Boundary Symbol Active Data Cell Tables 187
F.2 Calculation of Subframe Boundary Symbol Null Cells (Informative) 192
*ANNEX G* : TONE RESERVATION CARRIER INDICES ....193
G.1 Tone Reservation Carrier Indices 193
*ANNEX H* : PREAMBLE PARAMETERS FOR BOOTSTRAP....196
H.1 Preamble Structure Parameter Values 196
*ANNEX I* : TOTAL SYMBOL POWER....200
I.1 Preamble Symbol Frequency Domain Power 200
I.2 Data and Subframe Boundary Symbol Frequency Domain Power 201
*ANNEX J* : MISO ....207
J.1 MISO Frequency Domain Coefficients 207
*ANNEX K* : CHANNEL BONDING ....212
K.1 Introduction 212
K.2 Plain Channel Bonding 213
K.3 Channel Bonding with SNR Averaging 214
*ANNEX L* : MIMO ....216
L.1 Overview 216
L.2 FEC Coding 217

**L.3 Bit Interleaving 217**
**L.4 MIMO Mapping 217**
**L.4.1 Demultiplexer 217**
**L.4.2 Constellations 217**
**L.4.3 Constellation Superposition for LDM 218**
**L.5 Precoding 218**
**L.5.1 Stream Combining 219**
**L.5.2 I/Q Polarization Interleaving 220**
**L.5.3 Phase Hopping 220**
**L.6 Time Interleaver 220**
**L.7 Framer 221**
**L.8 Frequency Interleaving 221**
**L.9 Pilot Patterns 221**
**L.9.1 Pilot Antenna Encoding 221**
**L.9.2 Pilot Schemes 224**
**L.10 MISO 233**
**L.11 PAPR Reduction 233**
**L.12 Channel Bonding 233**
**L.13 L1 signalling for MIMO 233**
***ANNEX M* : EXAMPLE OF PEAK TO AVERAGE POWER RATIO REDUCTION ALGORITHMS.....235**
**M.1 PAPR Reduction Algorithms 235**
**M.2 TR Algorithm 235**
**M.3 ACE Algorithms 237**
**M.3.1 1-D ACE algorithm 237**
**M.3.2 2-D ACE Algorithm 239**
**M.3.3 2-D ACE Constellation Diagrams 241**
***ANNEX N* : TRANSMITTER IDENTIFICATION (TXID) .....245**
**N.1 Overview 245**
**N.2 Code Generation 245**
**N.2.1 Multiple Shift Registers 246**
**N.2.2 Clock Rate 247**
**N.2.3 Preloaded Values 247**
**N.2.4 Synchronization with Preamble Symbol 247**
**N.3 Code Transmission 248**
**N.3.1 BPSK Modulation 248**
**N.3.2 TxID Injection Level 248**
**N.4 Signaling Fields 249**

# Index of Figures

**Figure 4.1** Block diagram of the system architecture for one RF channel. 7
**Figure 4.2** Block diagram (simplified) of a single PLP system architecture. 8
**Figure 4.3** Block diagram (simplified) of a multiple PLP system architecture. 8
**Figure 4.4** Block diagram (simplified) of the LDM system architecture. 9
**Figure 4.5** Block diagram (simplified) of a channel bonded system. 10
**Figure 5.1** Block diagram of input formatting. 11
**Figure 5.2** Block diagram of baseband formatting. 12
**Figure 5.3** Baseband Packet structure showing Header, Payload and mapping example of ALP packets to a Baseband Packet. 12
**Figure 5.4** Baseband Packet Header structure details. 13
**Figure 5.5** Structure of Extension Field for the Mixed Extension Mode. 15
**Figure 5.6** Shift register of the PRBS encoder for baseband scrambling. 17
**Figure 6.1** Block diagram of BICM. 17
**Figure 6.2** Structure of FEC Frame when BCH or CRC is used as Outer Code. 18
**Figure 6.3** Structure of FEC Frame when no Outer Code is used. 18
**Figure 6.4** Shift register for CRC-32. 20
**Figure 6.5** Bit interleaver structure. 24
**Figure 6.6** Parity interleaved LDPC codeword bit groups. 25
**Figure 6.7** Write/Read operation of Type A block interleaving. 28
**Figure 6.8** Write operation of Part 1 Type B block interleaving for 256QAM. 29
**Figure 6.9** Read operation of Part 1 Type B block interleaving for 256QAM. 29
**Figure 6.10** Mapper structure. 30
**Figure 6.11** De-multiplexing of bits into sub-streams. 32
**Figure 6.12** Example 16-NUC for code rate 6/15. 33
**Figure 6.13** Example 1024-NUC for code rate 6/15. 34
**Figure 6.14** Block diagram of LDM encoding. 35
**Figure 6.15** Constellation superposition for two-layer LDM. 35
**Figure 6.16** Examples of (*a*, left) Core Layer and (*b*, right) Enhanced Layer constellations. 38
**Figure 6.17** Example combined constellation after normalization. 38
**Figure 6.18** Block diagram of L1-Basic protection. 39
**Figure 6.19** Block diagram of the L1-Detail protection. 39
**Figure 6.20** Format of data after LDPC encoding of L1-Basic/-Detail signaling. 42
**Figure 6.21** Parity interleaved LDPC codeword bit groups. 44
**Figure 6.22** Parity Repetition ($\boldsymbol{Nrepeat \leq Nldpc_parity}$). 46
**Figure 6.23** Parity Repetition ($\boldsymbol{Nrepeat > Nldpc_parity}$). 46
**Figure 6.24** Example 1 of parity puncturing after repetition. 48
**Figure 6.25** Example 2 of parity puncturing after repetition. 48
**Figure 6.26** Example of removal of zero-padding bits. 48
**Figure 6.27** Block interleaving scheme. 49
**Figure 6.28** Example of bit demultiplexing rule for 16-NUC. 49
**Figure 6.29** Segmentation of L1-Detail signaling. 51
**Figure 6.30** Additional parity for L1-Detail signaling. 52
**Figure 6.31** Repeated LDPC codeword. 52
**Figure 6.32** Additional parity generation for L1-Detail signaling ($N_{AP} \leq N_{punc}$). 54
**Figure 6.33** Additional parity generation for L1-Detail signaling ($N_{AP} > N_{punc}$). 54

**Figure 7.1** Block diagram of framing and interleaving. 55
**Figure 7.2** Block diagram for time interleaving for CTI Mode. 57
**Figure 7.3** Block diagram of the Convolutional Time Interleaver. 57
**Figure 7.4** Block diagram for time interleaving for HTI mode. 59
**Figure 7.5** Block diagram of the Cell Interleaver: (*a*) Linear writing operation, (*b*) Pseudo-random reading operation. 60
**Figure 7.6** Example of joint operation of TBI and CDL in the HTI. 62
**Figure 7.7** Block diagram of Twisted Block Interleaver: (*a*) linear writing operation, (*b*) diagonal-wise reading operation. 64
**Figure 7.8** Block diagram of Convolutional Delay Line used in the HTI. 65
**Figure 7.9** Example of HTI for **L1D_plp_HTI_inter_subframe** = 0 and 1, and for **L1D_plp_HTI_num_ti_blocks** = 0 and 1. 66
**Figure 7.10** Frame structure. 68
**Figure 7.11** Mapping of L1-Basic and L1-Detail into Preamble symbol(s). 71
**Figure 7.12** Data cell addressing when a Preamble symbol is associated with a subframe. 73
**Figure 7.13** Data cell addressing when a Preamble symbol is not associated with a subframe. 74
**Figure 7.14** Data carrier indices for null and active data carriers. 79
**Figure 7.15** Data cell indices used for illustrative multiplexing examples. 82
**Figure 7.16** Example of cell multiplexing for a single PLP per subframe. 82
**Figure 7.17** Example of time division multiplexing of PLPs. 83
**Figure 7.18** LDM Example #1 (1 Core PLP, 1 Enhanced PLP). 84
**Figure 7.19** LDM Example #2 (2 Core PLPs, 1 Enhanced PLP). 85
**Figure 7.20** LDM Example #3 (2 Core PLPs, 2 Enhanced PLPs). 85
**Figure 7.21** LDM Example #4 (1 Core PLP, 3 Enhanced PLPs). 86
**Figure 7.22** LDM Example #5 (3 Core PLPs, 1 Enhanced PLP). 87
**Figure 7.23** Example Insertion of Enhanced Layer dummy modulation values when the HTI mode is used with Layered-Division Multiplexing. 87
**Figure 7.24** Example of frequency division multiplexing of PLPs. 89
**Figure 7.25** Example of time and frequency division multiplexing of PLPs. 90
**Figure 7.26** Frequency interleaving overview. 90
**Figure 7.27** FI address generation scheme for the 8K FFT size. 91
**Figure 7.28** FI address generation scheme for the 16K FFT size. 91
**Figure 7.29** FI address generation scheme for the 32K FFT size. 92
**Figure 8.1** Block diagram of waveform generation. 94
**Figure 8.2** Reference sequence generator. 96
**Figure 8.3** Block diagram showing example MISO transmission. 102
**Figure 8.4** Illustration of the assignment of extra samples to the guard interval of each non-Preamble OFDM symbol in a frame. 107
**Figure 8.5** Illustration of remaining leftover extra samples being assigned to a cyclic postfix of the final OFDM symbol of the final subframe of the frame. 108
**Figure 9.1** Illustration of the time information position and the time information being transmitted in the Preamble. 118
**Figure 9.2** **L1D_plp_CTI_fec_block_start** graphical description 128
**Figure C.2.1** Constellation of QPSK. 172
**Figure C.2.2** Constellations of 16QAM. 172
**Figure C.2.3** Constellations of 64QAM. 173

**Figure C.2.4** Constellations of 256QAM. 173
**Figure C.2.5** Constellations of 1024QAM. 174
**Figure C.2.6** Constellations of 4096QAM. 174
**Figure E.1.1** Scattered pilot pattern SP3_2 (SISO, $D_X = 3$, $D_Y = 2$). 182
**Figure E.1.2** Scattered pilot pattern SP3_4 (SISO, $D_X = 3$, $D_Y = 4$). 182
**Figure E.1.3** Scattered pilot pattern SP4_2 (SISO, $D_X = 4$, $D_Y = 2$). 182
**Figure E.1.4** Scattered pilot pattern SP4_4 (SISO, $D_X = 4$, $D_Y = 4$). 183
**Figure E.1.5** Scattered pilot pattern SP6_2 (SISO, $D_X = 6$, $D_Y = 2$). 183
**Figure E.1.6** Scattered pilot pattern SP6_4 (SISO, $D_X = 6$, $D_Y = 4$). 183
**Figure E.1.7** Scattered pilot pattern SP8_2 (SISO, $D_X = 8$, $D_Y = 2$). 183
**Figure E.1.8** Scattered pilot pattern SP8_4 (SISO, $D_X = 8$, $D_Y = 4$). 184
**Figure E.1.9** Scattered pilot pattern SP12_2 (SISO, $D_X = 12$, $D_Y = 2$). 184
**Figure E.1.10** Scattered pilot pattern SP12_4 (SISO, $D_X = 12$, $D_Y = 4$). 184
**Figure E.1.11** Scattered pilot pattern SP16_2 (SISO, $D_X = 16$, $D_Y = 2$). 184
**Figure E.1.12** Scattered pilot pattern SP16_4 (SISO, $D_X = 16$, $D_Y = 4$). 185
**Figure E.1.13** Scattered pilot pattern SP24_2 (SISO, $D_X = 24$, $D_Y = 2$). 185
**Figure E.1.14** Scattered pilot pattern SP24_4 (SISO, $D_X = 24$, $D_Y = 4$). 185
**Figure E.1.15** Scattered pilot pattern SP32_2 (SISO, $D_X = 32$, $D_Y = 2$). 185
**Figure E.1.16** Scattered pilot pattern SP32_4 (SISO, $D_X = 32$, $D_Y = 4$). 186
**Figure K.1.1** Simple block diagram of channel bonding. 212
**Figure K.1.2** Transmitter side processing for channel bonding. 213
**Figure K.3.1** Cell exchange block. 214
**Figure L.1.1** MIMO block diagram. 216
**Figure L.1.2** MIMO MAP block diagram. 217
**Figure L.5.1** Generic MIMO Precoding block diagram. 218
**Figure L.5.2** Detailed MIMO precoding block diagram. 219
**Figure L.9.1** MIMO pilot scheme MP3_2 for Walsh-Hadamard pilot encoding. 226
**Figure L.9.2** MIMO pilot scheme MP3_4 for Walsh-Hadamard pilot encoding. 226
**Figure L.9.3** MIMO pilot scheme MP4_2 for Walsh-Hadamard pilot encoding. 226
**Figure L.9.4** MIMO pilot scheme MP4_4 for Walsh-Hadamard pilot encoding. 227
**Figure L.9.5** MIMO pilot scheme MP6_2 for Walsh-Hadamard pilot encoding. 227
**Figure L.9.6** MIMO pilot scheme MP6_4 for Walsh-Hadamard pilot encoding. 227
**Figure L.9.7** MIMO pilot scheme MP8_2 for Walsh-Hadamard pilot encoding. 227
**Figure L.9.8** MIMO pilot scheme MP8_4 for Walsh-Hadamard pilot encoding. 228
**Figure L.9.9** MIMO pilot scheme MP12_2 for Walsh-Hadamard pilot encoding. 228
**Figure L.9.10** MIMO pilot scheme MP12_4 for Walsh-Hadamard pilot encoding. 228
**Figure L.9.11** MIMO pilot scheme MP16_2 for Walsh-Hadamard pilot encoding. 228
**Figure L.9.12** MIMO pilot scheme MP16_4 for Walsh-Hadamard pilot encoding. 229
**Figure L.9.13** MIMO pilot scheme MP3_2 for null pilot encoding. 229
**Figure L.9.14** MIMO pilot scheme MP3_4 for null pilot encoding. 229
**Figure L.9.15** MIMO pilot scheme MP4_2 for null pilot encoding. 230
**Figure L.9.16** MIMO pilot scheme MP4_4 for null pilot encoding. 230
**Figure L.9.17** MIMO pilot scheme MP6_2 for null pilot encoding. 230
**Figure L.9.18** MIMO pilot scheme MP6_4 for null pilot encoding. 230
**Figure L.9.19** MIMO pilot scheme MP8_2 for null pilot encoding. 231
**Figure L.9.20** MIMO pilot scheme MP8_4 for null pilot encoding. 231

**Figure L.9.21** MIMO pilot scheme MP12_2 for null pilot encoding. ..... 231
**Figure L.9.22** MIMO pilot scheme MP12_4 for null pilot encoding. ..... 231
**Figure L.9.23** MIMO pilot scheme MP16_2 for null pilot encoding. ..... 232
**Figure L.9.24** MIMO pilot scheme MP16_4 for null pilot encoding. ..... 232
**Figure L.9.25** MIMO pilot scheme MP24_2 for null pilot encoding. ..... 232
**Figure L.9.26** MIMO pilot scheme MP24_4 for null pilot encoding. ..... 232
**Figure L.9.27** MIMO pilot scheme MP32_2 for null pilot encoding. ..... 233
**Figure L.9.28** MIMO pilot scheme MP32_4 for null pilot encoding. ..... 233
**Figure M.3.1** Implementation example of the ACE algorithm for 1-D constellations. ..... 238
**Figure M.3.2** Implementation example of the ACE algorithm for 2-D constellations. ..... 240
**Figure M.3.3** Constellation diagram for 16QAM when using the defined ACE algorithm. ..... 242
**Figure M.3.4** Constellation diagram for 64QAM when using the defined ACE algorithm. ..... 243
**Figure M.3.5** Constellation diagram for 256QAM when using the defined ACE algorithm. ... 244
**Figure N.1.1** TxID generation and injection into ATSC 3.0 host signals. ..... 245
**Figure N.2.1** TxID signal injection into the first Preamble symbol period (8K FFT). ..... 246
**Figure N.2.2** TxID signal injection into the first Preamble symbol period (16K FFT). ..... 246
**Figure N.2.3** TxID signal injection into the first Preamble symbol period (32K FFT). ..... 246
**Figure N.2.4** TxID code generator based on Gold sequence. ..... 246

# Index of Tables

**Table 5.1** OFI Description ... 14
**Table 5.2** **EXT_TYPE** Field Description for Extension Mode ... 16
**Table 6.1** Length of $K_{payload}$ (bits) for $N_{inner}$ = 64800 ... 19
**Table 6.2** Length of $K_{payload}$ (bits) for $N_{inner}$ = 16200 ... 19
**Table 6.3** BCH Polynomials ... 20
**Table 6.4** Structure of LDPC Encoding Used for Each of the Code Rates and Lengths ... 21
**Table 6.5** Coding Parameters for Type A: $N_{inner}$ = 64800 ... 23
**Table 6.6** Coding Parameters for Type A: $N_{inner}$ = 16200 ... 23
**Table 6.7** Coding Parameters for Type B ... 23
**Table 6.8** Block Interleaver Type for Codes of Length $N_{inner}$= 64800 Bits ... 26
**Table 6.9** Block Interleaver Type for Codes of Length $N_{inner}$= 16200 Bits ... 26
**Table 6.10** Type A Block Interleaver Configurations ... 26
**Table 6.11** Parameters for Type B Block Interleaver ... 28
**Table 6.12** Mandatory Modulation and Coding Combinations $N_{inner}$ = 64800 Bits ... 31
**Table 6.13** Mandatory Modulation and Coding Combinations $N_{inner}$ = 16200 Bits ... 31
**Table 6.14** Parameters for Bit-Mapping into Constellations ... 31
**Table 6.15** Power Distributions Between Layers for Various Injection Levels ... 36
**Table 6.16** Scaling and Normalizing Factors According to Enhanced Layer Injection Level ... 37
**Table 6.17** Configurations for L1-Basic and L1-Detail Signaling ... 40
**Table 6.18** Parameters for BCH Encoding of L1 Information ... 41
**Table 6.19** Parameters for Zero Padding ... 41
**Table 6.20** Shortening Pattern of Information Bit Group to be Padded ... 43
**Table 6.21** Group-wise Interleaving Pattern for all L1-Basic Modes, L1-Detail Modes 1 and 2 45
**Table 6.22** Group-wise Interleaving Pattern for L1-Detail Modes 3, 4, 5, 6 and 7 ... 45
**Table 6.23** Parameters for Repetition ... 46
**Table 6.24** Parameters for Puncturing ... 47
**Table 6.25** $K_{seg}$ for L1-Detail Signaling ... 50
**Table 7.1** Number of Carriers $NoC$ and Occupied Bandwidth ... 69
**Table 7.2** Number of Available Data Cells per Preamble Symbol ... 75
**Table 7.3** Number of Available Data Cells per Data Symbol ... 76
**Table 7.4** Number of Available Data Cells per Data Symbol ... 77
**Table 7.5** Total Number of Data Cells in a Subframe Boundary Symbol ... 78
**Table 7.6** Total Number of Data Cells in a Subframe Boundary Symbol ... 78
**Table 7.7** Example Parameters for the Cell Multiplexing of a Single PLP ... 82
**Table 7.8** Example Parameters for Time Division Multiplexing of PLPs ... 83
**Table 7.9** Example Parameters for Frequency Division Multiplexing of PLPs ... 88
**Table 7.10** Example Parameters for Time and Frequency Division Multiplexing of PLPs ... 89
**Table 7.11** Values of $Mmax$ for the Frequency Interleaver ... 92
**Table 7.12** Wire Permutations for the 8K FFT Size ... 93
**Table 7.13** Wire Permutations for the 16K FFT Size ... 93
**Table 7.14** Wire Permutations for the 32K FFT Size ... 93
**Table 8.1** Presence of the Various Types of Pilots in Each Type of Symbol ... 95
**Table 8.2** Parameters $D_X$ and $D_Y$ Defining the SISO Scattered Pilot Patterns ... 96
**Table 8.3** Allowed Scattered Pilot Pattern for Each Combination of FFT Size and Guard Interval Pattern in SISO Mode ... 97

**Table 8.4** Number of Common Continual Pilots in Each FFT Size ..... 98
**Table 8.5** Boosting for the Common Continual Pilots ..... 98
**Table 8.6** Exact Power (dB) and Approximate Amplitudes of the Preamble Pilots ..... 100
**Table 8.7** Approximate Elementary Periods *T* ..... 104
**Table 8.8** OFDM Parameters ..... 105
**Table 8.9** Duration of the Guard Intervals in Samples ..... 106
**Table 9.1** Defined Values of **bsr_coefficient** ..... 109
**Table 9.2** L1-Basic Signaling Fields and Syntax ..... 109
**Table 9.3** Signaling Format for **L1B_mimo_scattered_pilot_encoding** ..... 110
**Table 9.4** Signaling Format for **L1B_time_info_flag** ..... 110
**Table 9.5** Signaling Format for **L1B_papr_reduction** ..... 111
**Table 9.6** Signaling Format for **L1B_L1_Detail_fec_type** ..... 113
**Table 9.7** Signaling Format for **L1B_additional_parity_mode** ..... 113
**Table 9.8** L1-Detail Signaling Fields and Syntax ..... 115
**Table 9.9** Signaling Format for **L1D_miso** and **L1B_first_sub_miso** ..... 119
**Table 9.10** Signaling Format for **L1D_fft_size** and **L1B_first_sub_fft_size** ..... 119
**Table 9.11** Signaling format for **L1D_guard_interval** and **L1B_first_sub_guard_interval** ..... 120
**Table 9.12** Signaling Format for **L1D_scattered_pilot_pattern** and **L1B_first_sub_scattered_pilot_pattern** for SISO ..... 120
**Table 9.13** Signaling Format for **L1D_scattered_pilot_pattern** and **L1B_first_sub_scattered_pilot_pattern** for MIMO ..... 120
**Table 9.14** Signaling Format for **L1D_scattered_pilot_boost** (power in dB) ..... 121
**Table 9.15** Equivalent Signaling Format for **L1D_scattered_pilot_boost** (amplitude) ..... 121
**Table 9.16** Signaling Format for **L1D_plp_scrambler_type** ..... 123
**Table 9.17** Signaling Format for **L1D_plp_fec_type** ..... 123
**Table 9.18** Signaling Format for **L1D_plp_mod** for SISO ..... 123
**Table 9.19** Signaling Format for **L1D_plp_mod** for MIMO ..... 123
**Table 9.20** Signaling Format for **L1D_plp_cod** ..... 124
**Table 9.21** Signaling Format for **L1D_plp_TI_mode** ..... 124
**Table 9.22** Signaling Format for **L1D_plp_ldm_injection_level** ..... 125
**Table 9.23** Signaling Format for **L1D_plp_channel_bonding_format** ..... 126
**Table 9.24** Signaling Format for **L1D_plp_CTI_depth** ..... 127
**Table A.1.1** Rate = 2/15 ($N_{inner}$ = 64800) ..... 130
**Table A.1.2** Rate = 3/15 ($N_{inner}$ = 64800) ..... 131
**Table A.1.3** Rate = 4/15 ($N_{inner}$ = 64800) ..... 132
**Table A.1.4** Rate = 5/15 ($N_{inner}$ = 64800) ..... 133
**Table A.1.5** Rate = 6/15 ($N_{inner}$ = 64800) ..... 134
**Table A.1.6** Rate = 7/15 ($N_{inner}$ = 64800) ..... 135
**Table A.1.7** Rate = 8/15 ($N_{inner}$ = 64800) ..... 136
**Table A.1.8** Rate = 9/15 ($N_{inner}$ = 64800) ..... 137
**Table A.1.9** Rate = 10/15 ($N_{inner}$ = 64800) ..... 138
**Table A.1.10** Rate = 11/15 ($N_{inner}$ = 64800) ..... 139
**Table A.1.11** Rate = 12/15 ($N_{inner}$ = 64800) ..... 140
**Table A.1.12** Rate = 13/15 ($N_{inner}$ = 64800) ..... 141
**Table A.2.1** Rate = 2/15 ($N_{inner}$ = 16200) ..... 142

**Table A.2.2** Rate = 3/15 ($N_{inner}$ = 16200) ... 142
**Table A.2.3** Rate = 4/15 ($N_{inner}$ = 16200) ... 142
**Table A.2.4** Rate = 5/15 ($N_{inner}$ = 16200) ... 143
**Table A.2.5** Rate = 6/15 ($N_{inner}$ = 16200) ... 143
**Table A.2.6** Rate = 7/15 ($N_{inner}$ = 16200) ... 143
**Table A.2.7** Rate = 8/15 ($N_{inner}$ = 16200) ... 144
**Table A.2.8** Rate = 9/15 ($N_{inner}$ = 16200) ... 144
**Table A.2.9** Rate = 10/15 ($N_{inner}$ = 16200) ... 144
**Table A.2.10** Rate = 11/15 ($N_{inner}$ = 16200) ... 145
**Table A.2.11** Rate = 12/15 ($N_{inner}$ = 16200) ... 145
**Table A.2.12** Rate = 13/15 ($N_{inner}$ = 16200) ... 146
**Table B.1.1** QPSK ($N_{inner}$ = 64800) ... 147
**Table B.1.2** 16QAM ($N_{inner}$ = 64800) ... 150
**Table B.1.3** 64QAM ($N_{inner}$ = 64800 bits) ... 152
**Table B.1.4** 256QAM ($N_{inner}$ = 64800) ... 154
**Table B.1.5** 1024QAM ($N_{inner}$ = 64800) ... 156
**Table B.1.6** 4096QAM ($N_{inner}$ = 64800) ... 158
**Table B.2.1** QPSK ($N_{inner}$ = 16200) ... 160
**Table B.2.2** 16QAM (Code length = 16200 bits) ... 161
**Table B.2.3** 64QAM ($N_{inner}$ = 16200) ... 162
**Table B.2.4** 256QAM ($N_{inner}$ = 16200) ... 163
**Table C.1.1** QPSK Definition Table for All Code Rates ... 164
**Table C.1.2** 16QAM Definition Table for Code Rates 2/15-7/15 ... 164
**Table C.1.3** 16QAM Definition Table for Code Rates 8/15-13/15 ... 164
**Table C.1.4** 64QAM Definition Table for Code Rates 2/15-7/15 ... 165
**Table C.1.5** 64QAM Definition Table for Code Rates 8/15-13/15 ... 165
**Table C.1.6** 256QAM Definition Table for Code Rates 2/15-7/15 ... 166
**Table C.1.7** 256QAM Definition Table for Code Rates 8/15-13/15 ... 167
**Table C.1.8** 1024QAM Definition Table for Code Rates 2/15-7/15 ... 169
**Table C.1.9** 1024QAM Definition Table for Code Rates 8/15-13/15 ... 169
**Table C.1.10** 4096QAM Definition Table for Code Rates 2/15-7/15 ... 170
**Table C.1.11** 4096QAM Definition Table for Code Rates 8/15-13/15 ... 171
**Table C.3.1** Constellation Mapping for the Real Part of 1024QAM ... 175
**Table C.3.2** Constellation Mapping for the Imaginary Part of 1024QAM ... 175
**Table C.3.3** Constellation Mapping for the Real Part of 4096QAM ... 176
**Table C.3.4** Constellation Mapping for the Imaginary Part of 4096QAM ... 177
**Table D.1.1** Common CP Absolute Carrier Indices $CP_{32}$ ... 178
**Table D.1.2** Common CP Absolute Carrier Indices $CP_{16}$ ... 179
**Table D.1.3** Common CP Absolute Carrier Indices $CP_{8}$ ... 179
**Table D.1.4** Additional Scattered Pilot Bearing Continual Pilot Relative Carrier Indices for Each FFT Size and Scattered Pilot Pattern Combination ... 180
**Table D.1.5** Additional Scattered Pilot Bearing Continual Pilot Relative Carrier Indices for SP32_4 in 8K FFT ... 181
**Table F.1.1** Number of Active Data Cells in a SBS when $C_{red_coeff}=0$ ... 187
**Table F.1.2** Number of Active Data Cells in a SBS when $C_{red_coeff}=0$ ... 188
**Table F.1.3** Number of Active Data Cells in a SBS when $C_{red_coeff}=1$ ... 188

**Table F.1.4** Number of Active Data Cells in a SBS when $C_{red_coeff}=1$ ..... 189
**Table F.1.5** Number of Active Data Cells in a SBS when $C_{red_coeff}=2$ ..... 189
**Table F.1.6** Number of Active Data Cells in a SBS when $C_{red_coeff}=2$ ..... 190
**Table F.1.7** Number of Active Data Cells in a SBS when $C_{red_coeff}=3$ ..... 190
**Table F.1.8** Number of Active Data Cells in a SBS when $C_{red_coeff}=3$ ..... 191
**Table F.1.9** Number of Active Data Cells in a SBS when $C_{red_coeff}=4$ ..... 191
**Table F.1.10** Number of Active Data Cells in a SBS when $C_{red_coeff}=4$ ..... 192
**Table G.1.1** Table Indices Corresponding to the Set of Reserved Carriers for PAPR Reduction According to Each Type of Symbol ..... 193
**Table G.1.2** Set of Carriers Reserved for PAPR reduction for All Symbols Except the First Preamble Symbol, the Other ($N_P$ – 1) Preamble Symbols of $D_X$ = 3, $D_X$ = 4, and $D_X$ = 8, and Subframe Boundary Symbols of $D_X$ = 3, $D_X$ = 4, and $D_X$ = 8 ..... 194
**Table G.1.3** Set of Carriers Reserved for PAPR reduction in Preamble Symbols of $D_X$ = 3, $D_X$ = 4, and $D_X$ = 8 Except the First Preamble Symbol and in Subframe Boundary Symbols of $D_X$ = 3, $D_X$ = 4, and $D_X$ = 8 ..... 195
**Table H.1.1** Meaning of Signaled Values of **preamble_structure** ..... 196
**Table I.1.1** Frequency Domain Total Power of the Preamble Symbol ($P_{\mathrm{Preamble,l}}$) ..... 200
**Table I.2.1** Frequency Domain Total Power of Each Data and Subframe Boundary Symbol ($P_{\mathrm{data,m}}$) when $C_{red_coeff}$=0 ..... 201
**Table I.2.2** Frequency Domain Total Power of Each Data and Subframe Boundary Symbol ($P_{\mathrm{data,m}}$) when $C_{red_coeff}$=1 ..... 202
**Table I.2.3** Frequency Domain Total Power of Each Data and Subframe Boundary Symbol ($P_{\mathrm{data,m}}$) when $C_{red_coeff}$=2 ..... 203
**Table I.2.4** Frequency Domain Total Power of Each Data and Subframe Boundary Symbol ($P_{\mathrm{data,m}}$) when $C_{red_coeff}$=3 ..... 204
**Table I.2.5** Frequency Domain Total Power of Each Data and Subframe Boundary Symbol ($P_{\mathrm{data,m}}$) when $C_{red_coeff}$=4 ..... 205
**Table J.1.1** Time Domain Impulse Response Vectors for $NMISO$=64 ..... 207
**Table J.1.2** Time Domain Impulse Response Vectors for $NMISO$=256 ..... 208
**Table L.4.1** Bits Per Cell Unit and Modulation for MIMO ..... 218
**Table L.5.1** Rotation Angle for the Stream Combining ..... 220
**Table L.9.1** MIMO Pilot Antenna Encoding Overview ..... 222
**Table L.9.2** MIMO Pilot Schemes with Equivalent SISO Pilot Schemes and $D_X$ and $D_Y$ Values ..... 224
**Table L.9.3** Allowed Scattered Pilot Patterns for Each Allowed Combination of FFT Size and Guard Interval Length in MIMO Mode with Walsh-Hadamard Encoding ..... 225
**Table_L.9.4** Allowed Scattered Pilot Patterns for Each Allowed Combination of FFT Size and Guard Interval Length in MIMO Mode with Null Pilot Encoding ..... 225
**Table M.3.1** ACE Algorithm Used for Each Modulation and Code Rate Combination ..... 237
**Table M.3.2** Values of Angle θ of ACE Algorithm for 2-Dimensional Constellations ..... 241
**Table N.2.1** Code Sequence Generator Preloading ..... 247
**Table N.3.1** TxID Injection Levels Below Host ATSC 3.0 Preamble ..... 249

# ATSC Standard: Physical Layer Protocol

## 1. SCOPE

This Standard describes the RF/Transmission of a physical layer waveform. This waveform enables flexible configurations of physical layer resources to target a variety of operating modes. The intent is to signal the applied technologies and allow for future technology adaptation.

### 1.1 Introduction and Background

The ATSC physical layer protocol is intended to offer far more flexibility, robustness and efficient operations than the ATSC A/53 standard, and as a result it is non-backwards compatible with A/53. This physical layer allows broadcasters to choose from among a wide variety of physical layer parameters for personalized broadcaster performance that can satisfy many different broadcaster needs. There is the capability to have high-capacity/low-robustness and low-capacity/high-robustness modes in the same emission. Technologies can be selected for special use cases like Single Frequency Networks, Multiple Input Multiple Output channel operation, channel bonding and more, well beyond a single transmitting tower. There is a large range of selections for robustness including, but not limited to, a wide range of guard interval lengths, forward error correction code lengths and code rates.

Significant flexibility comes from a signaling structure that allows the physical layer to change technologies and evolve over time, while maintaining support of other ATSC systems. The starting point of this change is a physical layer offering highly spectral efficient operation with strong robustness across many different modes of operation.

### 1.2 Organization

This document is organized as follows:

- Section 1 – The scope of this document and general introduction
- Section 2 – References and applicable documents
- Section 3 – Definition of terms, acronyms, and abbreviations used
- Section 4 – System overview
- Section 5 – The specification in detail for the Input Formatting part
- Section 6 – The specification in detail for the Bit-Interleaved Coded Modulation part
- Section 7 – The specification in detail for the Framing and Interleaving part
- Section 8 –The specification in detail for the Waveform Generation part
- Section 9 – The specification in detail for the Physical Layer Signaling
- Annex A– LDPC Codes
- Annex B– Bit Interleaver sequences
- Annex C– Constellation Definitions and Figures
- Annex D– Continual Pilot (CP) Patterns
- Annex E– Scattered Pilot (SP) Patterns
- Annex F– Number of Active Carriers in Subframe Boundary Symbols
- Annex G– Tone Reservation Carrier Indices
- Annex H– Preamble Parameters for Bootstrap

- Annex I– Total Symbol Power
- Annex J– MISO
- Annex K– Channel Bonding of multiple RF channels
- Annex L– MIMO
- Annex M– PAPR Reduction Algorithms (Informative)
- Annex N– Transmitter Identification (TxID)

## 2. REFERENCES

All referenced documents are subject to revision. Users of this Standard are cautioned that newer editions might or might not be compatible.

### 2.1 Normative References

The following documents, in whole or in part, as referenced in this document, contain specific provisions that are to be followed strictly in order to implement a provision of this Standard.

[1] IEEE: "Use of the International Systems of Units (SI): The Modern Metric System," Doc. SI 10, Institute of Electrical and Electronics Engineers, New York, NY.

[2] ATSC: "ATSC Standard: System Discovery and Signaling," Doc. A/321:2022-03, Advanced Television Systems Committee, Washington, DC, 31 March 2022.

[3] ATSC: "ATSC Standard: Link-Layer Protocol," Doc. A/330:2022-03, Advanced Television Systems Committee, Washington, DC, 31 March 2022.

### 2.2 Informative References

[4] ATSC: "ATSC Standard: Scheduler / Studio-Transmitter Link," Doc. A/324:2022-03, Advanced Television Systems Committee, Washington, DC, 31 March 2022.

[5] ATSC: "ATSC Standard: Signaling, Delivery, Synchronization, and Error Protection," Doc. A/331:2022-03, Advanced Television Systems Committee, Washington, DC, 31 March 2022.

[6] IEEE: "IEEE Standard for a Precision Clock Synchronization Protocol for Networked Measurement and Control Systems," Doc. 1588, Institute of Electrical and Electronics Engineers, New York, NY, approved 27 March 2008.

## 3. DEFINITION OF TERMS

With respect to definition of terms, abbreviations, and units, the practice of the Institute of Electrical and Electronics Engineers (IEEE) as outlined in the Institute's published standards [1] shall be used. Where an abbreviation is not covered by IEEE practice or industry practice differs from IEEE practice, the abbreviation in question will be described in Section 3.3 of this document.

### 3.1 Compliance Notation

This section defines compliance terms for use by this document:

**shall** – This word indicates specific provisions that are to be followed strictly (no deviation is permitted).

**shall not** – This phrase indicates specific provisions that are absolutely prohibited.

**should** – This word indicates that a certain course of action is preferred but not necessarily required.

**should not** – This phrase means a certain possibility or course of action is undesirable but not prohibited.

## 3.2 Treatment of Syntactic Elements

This document contains symbolic references to syntactic elements used in the audio, video, and transport coding subsystems. These references are typographically distinguished by the use of a different font (e.g., restricted), may contain the underscore character (e.g., sequence_end_code) and may consist of character strings that are not English words (e.g., dynrng).

### 3.2.1 Reserved Elements

One or more reserved bits, symbols, fields, or ranges of values (i.e., elements) may be present in this document. These are used primarily to enable adding new values to a syntactical structure without altering its syntax or causing a problem with backwards compatibility, but they also can be used for other reasons.

The ATSC default value for reserved bits is '1'. There is no default value for other reserved elements. Use of reserved elements except as defined in ATSC Standards or by an industry standards setting body is not permitted. See individual element semantics for mandatory settings and any additional use constraints. As currently-reserved elements may be assigned values and meanings in future versions of this Standard, receiving devices built to this version are expected to ignore all values appearing in currently-reserved elements to avoid possible future failure to function as intended.

## 3.3 Acronyms, Abbreviations and Mathematical Operators

The following acronyms and abbreviations are used within this document.

**8K** 8192 point FFT size
**16K** 16384 point FFT size
**32K** 32768 point FFT size
**ACE** Active Constellation Extension
**ALP** ATSC Link-layer Protocol
**AP** Additional Parity
**ATSC** Advanced Television Systems Committee
**AWGN** Additive White Gaussian Noise
**BBP** BaseBand Packet
**BCH** Bose, Chaudhuri, Hocquenghem
**BICM** Bit-Interleaved Coded Modulation
**BIL** Bit InterLeaver
**bpcu** bits per cell unit
**BPSK** Binary Phase Shift Keying
**BSID** Broadcast Stream ID
**BSR** Baseband Sampling Rate
**CDL** Convolutional Delay Line
**CL** Core Layer
**Cod** Code rate
**CP** Continual Pilot
**CRC** Cyclic Redundancy Check
**CTI** Convolutional Time Interleaver
**dB** deciBel

| | |
|---|---|
| **DC** | Direct Current |
| **DRC** | Dedicated Return Channel |
| **DSBSS** | Direct Sequence Buried Spread Spectrum |
| **EL** | Enhanced Layer |
| **FEC** | Forward Error Correction |
| **FI** | Frequency Interleaver |
| **FBSR** | FeedBack Shift Register |
| **FDM** | Frequency Division Multiplexing |
| **FFT** | Fast Fourier Transform |
| **FIFO** | First-In-First-Out |
| **GI** | Guard Interval |
| **HTI** | Hybrid Time Interleaver |
| **IF** | Interleaving Frame |
| **IFFT** | Inverse Fast Fourier Transform |
| **ISO** | International Organization for Standardization |
| **IU** | Interleaving Unit |
| **L1** | Layer 1 |
| **LDM** | Layered Division Multiplexing |
| **LDPC** | Low Density Parity Check |
| **LLS** | Low Level Signaling |
| **LPF** | Low Pass Filter |
| **LSB** | Least Significant Bit |
| **Mbps** | Megabits per second |
| **MHz** | Megahertz |
| **MIMO** | Multiple Input Multiple Output |
| **MISO** | Multiple Input Single Output |
| **Mod** | Modulation |
| **MSB** | Most Significant Bit |
| **ms** | milliseconds |
| **N/A** | Not Allowed |
| **NoA** | Number of Active (cells) |
| **NoC** | Number of (useful) Carriers |
| **NUC** | Non-Uniform Constellation |
| **OFDM** | Orthogonal Frequency Division Multiplexing |
| **OFI** | Optional Field Indicator |
| **OTA** | Over The Air |
| **PAM** | Pulse Amplitude Modulation |
| **PAPR** | Peak-to-Average Power Ratio |
| **PH** | Phase Hopping |
| **PLP** | Physical Layer Pipe |
| **PRBS** | Pseudo Random Binary Sequence |
| **PTP** | Precision Time Protocol |

**QAM** Quadrature Amplitude Modulation
**QPSK** Quadrature Phase Shift Keying
**RF** Radio Frequency
**RFU** Reserved for Future Use
**SBS** Subframe Boundary Symbol
**SFN** Single Frequency Network
**SIMO** Single Input Multiple Output
**SISO** Single Input Single Output
**SNR** Signal-to-Noise Ratio
**SP** Scattered Pilot
**STL** Studio-to-Transmitter Link
**TBI** Twisted Block Interleaver
**TDM** Time Division Multiplexing
**TI** Time Interleaver
**TR** Tone Reservation
**TxID** Transmitter Identification
**XOR** eXclusive OR
$\lfloor X \rfloor$ The greatest integer less than or equal to $X$

## 3.4 Terms

The following terms are used within this document.

**Base Field** – The first portion of a Baseband Packet Header.

**Baseband Packet** – A set of $K_{payload}$ bits which form the input to a FEC encoding process. There is one Baseband Packet per FEC Frame.

**Baseband Packet Header** – The header portion of a Baseband Packet.

**Block Interleaver** – An interleaver where the input data is written along the rows of a memory configured as a matrix, and read out along the columns.

**Broadcast Stream ID (BSID)** – A 16-bit value that identifies the aggregate contents of a broadcast signal. Each transmitted signal that is unique (has content that is different from another signal) has a unique BSID; e.g., a signal translated onto a different frequency has the same BSID.

**Cell** – One set of encoded I/Q components in a constellation.

**Cell Interleaver** – An interleaver operating at the cell level.

**Combined PLP** – A PLP after processing by the LDM injection block.

**Concatenated Code** – A code having an Outer Code followed by an Inner Code.

**Constellation** – A set of encoded (I component/Q component) points in the I/Q plane.

**Core Layer** – The first layer of a 2-layer LDM system. The only layer in a non-LDM system.

**Core PLP** – A PLP belonging to the Core Layer.

**Data Payload Symbols** – Data and Subframe Boundary Symbols (i.e. non-Preamble symbols).

**Enhanced Layer** – The second layer of a 2-layer LDM system.

**Enhanced PLP** – A PLP belonging to the Enhanced Layer.

**Extension Field** – The third portion of a Baseband Packet Header.

**FEC Frame** – A single Baseband Packet with its associated FEC parity bits attached, having a total size of 64800 or 16200 bits (per FEC Frame).

**FEC Block** – A FEC Frame after mapping to cells.

**Frequency Interleaver** – An interleaver which takes cells and interleaves them over a particular symbol.

**Interleaver** – A device used to counteract the effect of burst errors.

**Inner Code** – One code of a Concatenated Code system.

**Layered Division Multiplexing** – A multiplexing scheme where multiple PLPs are combined in layers with a specific power ratio.

**ModCod** – A combination of modulation and code rate that together determine the robustness of the PLP and the size of the Baseband Packet.

**Non-Uniform Constellation** – A constellation with a non-uniform spread of constellation points.

**Optional Field** – The second portion of a Baseband Packet Header.

**Outer Code** – One code of a Concatenated Code system.

**Physical Layer Pipe** – A structure specified to an allocated capacity and robustness that can be adjusted to broadcaster needs.

**Preamble** – The portion of the frame that carries L1 signaling data for the frame.

**Systematic** – A property of a code in which the codeword is composed of the original data in its sequential order followed by the parity data for the codeword.

**Time Interleaver** – An interleaver which takes cells and interleaves them over a particular time period.

**TI Block** – An integer number of FEC Blocks.

**Twisted Block Interleaver** – An interleaver that performs intra-subframe interleaving by interleaving TI Blocks.

**reserved** – Set aside for future use by a Standard.

## 4. SYSTEM OVERVIEW

### 4.1 Features

The ATSC physical layer protocol is intended to offer the flexibility to choose among many different operating modes depending on desired robustness/efficiency tradeoffs. It is built on the foundation of OFDM modulation with a suite of LDPC FEC codes, of which there are 2 code lengths and 12 code rates defined. There are three basic modes of multiplexing: time, layered and frequency, along with three transmission modes of SISO, MISO and MIMO. Signal protection starts with 12 selectable guard interval lengths to offer long echo protection lengths. Channel estimation can be done with 16 scattered pilot patterns along with continual pilot patterns. Three FFT sizes (8K, 16K and 32K) offer a choice of Doppler protection depending on the anticipated device mobility.

Supported bit rates in a 6MHz channel range from less than 1Mbps in the lowest-capacity most-robust mode, up to over 57Mbps when using the highest-capacity parameters. Data are carried in Physical Layer Pipes (PLPs), which are data structures that can be configured for a wide range of trade-offs between signal robustness and channel capacity utilization for a given data payload. Multiple PLPs can be used to carry different streams of data, all of which are required to assemble a complete delivered product. In addition, data streams required to assemble multiple delivered products can share PLPs if those data streams are to be carried with the same levels of robustness. Combinations of data streams necessary to assemble a particular delivered product are limited to carriage on a maximum of 4 PLPs. These capabilities enable scenarios such as robust

audio, video, enhanced video, and application data each being sent on an individual PLP at different robustness levels. For channel impairment mitigation, the time interleaver can be configured for intra-subframe interleaving up to 200 ms (up to 400 ms in some limited modes using extended interleaving) and larger depths in inter-subframe interleaving for low-bit rate streams. Frequency interleaving can be used throughout the channel bandwidth on a per symbol basis to separate burst errors in the frequency domain.

These pieces of technology are combined in an order described in the next section. The purpose of the physical layer is to offer a wide range of tools for broadcasters to choose the operating mode(s) that best fits their needs and targeted devices. This toolbox of technology is expected to grow over time and the ability to upgrade or swap out new technology is enabled with the extensive and extensible signaling in the Preamble. Broadcasters will have the ability to try new technologies out without breaking an existing service.

The bootstrap, as described in [2], shows that each frame can be different, including non-ATSC related signals. The time of the next similar frame is signaled so that the existing service can continue. This standard describes the physical layer downlink signals after the bootstrap.

## 4.2 System Architecture

A block diagram of the main data flow for the total transmitter system architecture is shown in Figure 4.1. The system architecture consists of four main parts: Input Formatting, Bit-Interleaved Coded Modulation (BICM), Framing and Interleaving, and Waveform Generation. For simplicity, control and signaling information flow is not shown in this diagram.

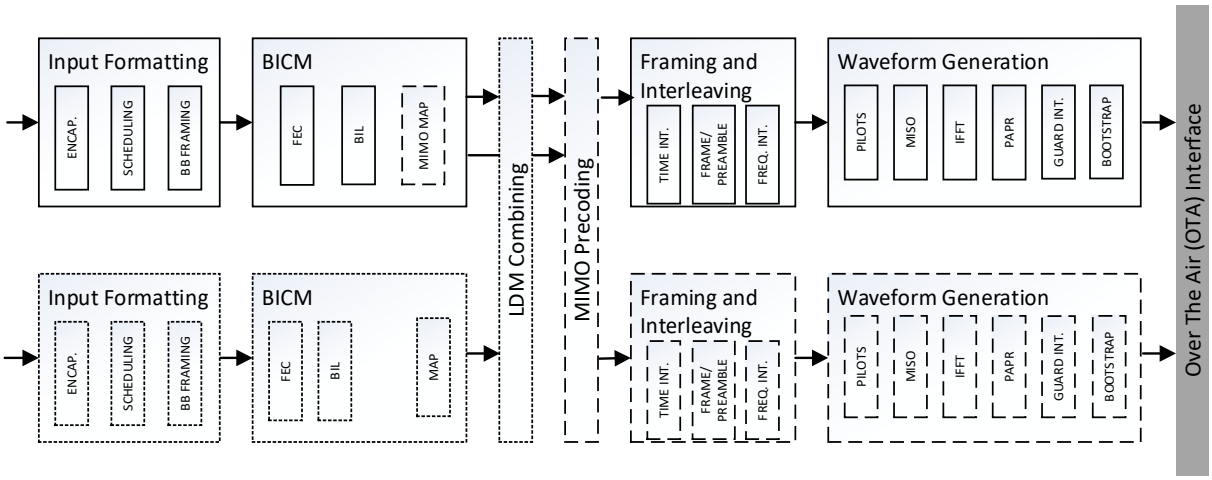


**Figure 4.1** Block diagram of the system architecture for one RF channel.

In this specification, Input Formatting is described in Section 5, BICM is described in Section 6, LDM Combining in Section 6.4, Framing and Interleaving in Section 7, and Waveform Generation in Section 8. The signaling required to configure all of the blocks is described in Section 9. MIMO Precoding is described in Annex L.

Not all blocks are used in each configuration. In Figure 4.1 the solid lines show blocks common to all configurations, dotted lines show blocks specific to LDM (MIMO blocks are not used) and dashed lines show blocks specific to MIMO (LDM blocks are not used).

Although not shown in Figure 4.1, there is a SFN/STL distribution interface located between the Scheduling and Baseband Framing blocks. The definition of interface format for SFNs and transmission from the studio to the tower is defined in [4].

A key concept in the Input Formatting and BICM blocks is the PLP (Physical Layer Pipe) which is a stream of data encoded with a specific modulation, code rate and length. Figure 4.2 and Figure 4.3 show simplified block diagrams when there is only a single PLP (Figure 4.2) and when there are 4 PLPs (Figure 4.3), respectively. For each PLP a separate Input Formatting and BICM block is used. It is noted that after the Framing and Interleaving block there is only one stream of data, as the PLPs have been multiplexed onto OFDM symbols and then arranged in frames.

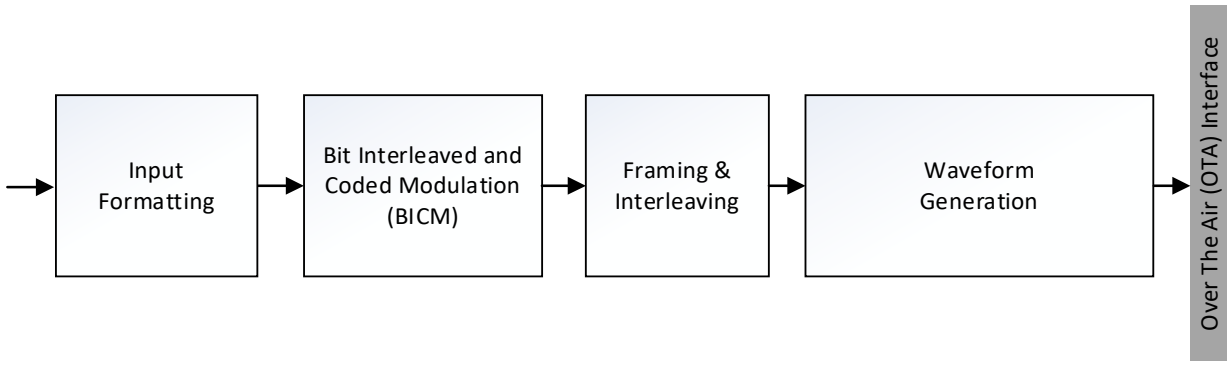


**Figure 4.2** Block diagram (simplified) of a single PLP system architecture.

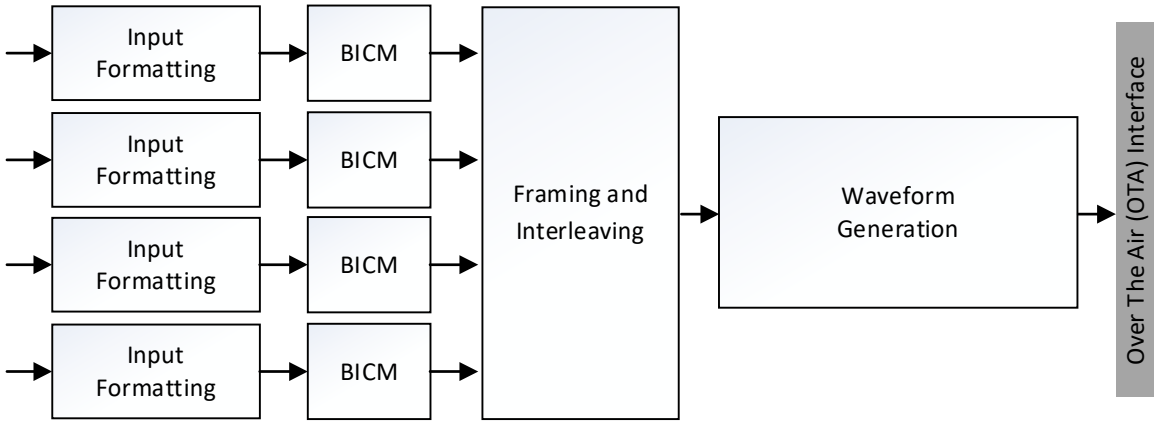


**Figure 4.3** Block diagram (simplified) of a multiple PLP system architecture.

Although there are multiple methods of multiplexing the input data supported in this standard, two are described very briefly in this section, specifically Time Division Multiplexing (TDM) and Layered Division Multiplexing (LDM). The system architecture block diagrams for these two methods show how the overall system architecture diagram can be simplified for specific configurations.

In the TDM system architecture there are four main blocks: Input Formatting, Bit-Interleaved Coded Modulation (BICM), Framing and Interleaving and Waveform Generation. Input data is formatted in the Input Formatting block, and forward error correction applied and mapped to constellations in the BICM block. Interleaving, both time and frequency, and frame creation are done in the Framing and Interleaving block. It is in this block that the time division multiplexing

of the multiple PLPs is done. Finally, the output waveform is created in the Waveform Generation block. The TDM system architecture can be realized using the simplified block diagram shown in Figure 4.3.

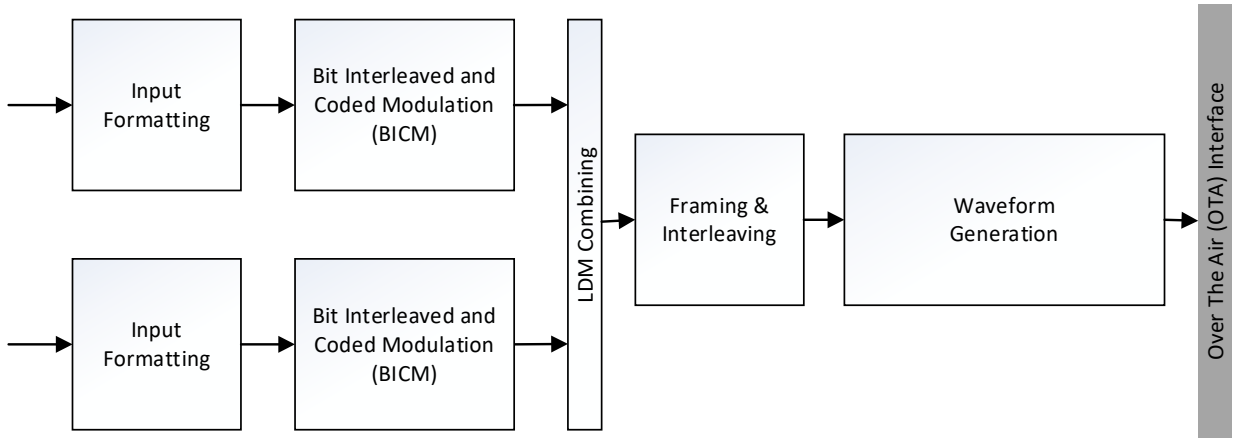


**Figure 4.4** Block diagram (simplified) of the LDM system architecture.

In the LDM system architecture, shown in the simplified block diagram in Figure 4.4, in addition to the four blocks that have already been shown in the TDM system, there is an additional block LDM Combining. Before this block there are two corresponding Input Formatting and BICM blocks, one for each of the two LDM layers. After combining the data from each layer, the data passes through the Framing and Interleaving block followed by the Waveform Generation block.

This standard also offers the option to use multiple RF channels through channel bonding, described in Annex K and shown graphically in Figure 4.5. Compared to the TDM architecture, at the transmitter side there is an additional block, Stream Partitioning. The high data rate input stream is partitioned in this block into two separate streams, each passing through a BICM, Framing and Interleaving and Waveform Generation block. Each stream is output onto a separate RF channel. At the receiver side, the outputs of the two RF channels are then combined to achieve greater data rates than can be achieved in one RF channel alone.

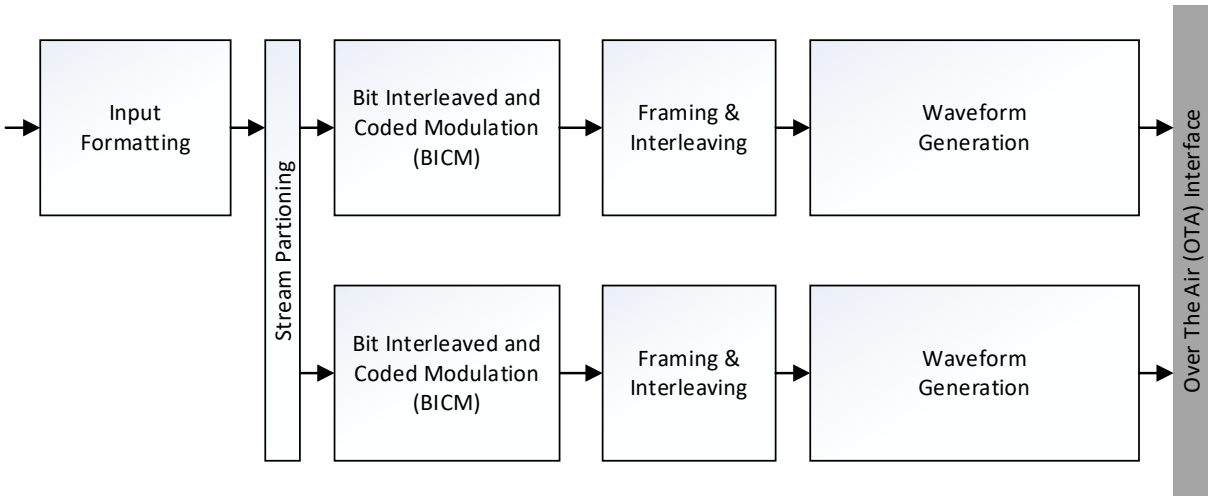


**Figure 4.5** Block diagram (simplified) of a channel bonded system.

### 4.3 Central Concepts

This standard has two concepts at its core: flexibility and efficiency.

For flexibility, the number of modulation and coding combinations offers a breadth of choice for operating point that have not been available in any previous broadcasting standard. Multiple multiplexing methods give options to the broadcaster to configure the transmission chain like never before. Individual blocks may be turned on and off with an extensive set of signaling. Furthermore, this standard has allowed "room to grow" as technologies evolve so that the standard may be extended in the future.

For efficiency, new forward error correcting options with the adoption of non-uniform-constellations has brought the operation of the BICM closer to the theoretical Shannon Limit; offering over 1dB of gain compared to the use of uniform constellations using the same operating parameters.

## 5. INPUT FORMATTING

The input formatting consists of three blocks: encapsulation and compression of data, baseband framing and the scheduler. This is shown in Figure 5.1. The dotted line represents the flow of control information, while the solid lines represent the flow of data.

The encapsulation and compression operation of data is described in detail in Section 5.1, the operation of the scheduler is described in [4], and the Baseband Packet construction is described in Section 5.2.

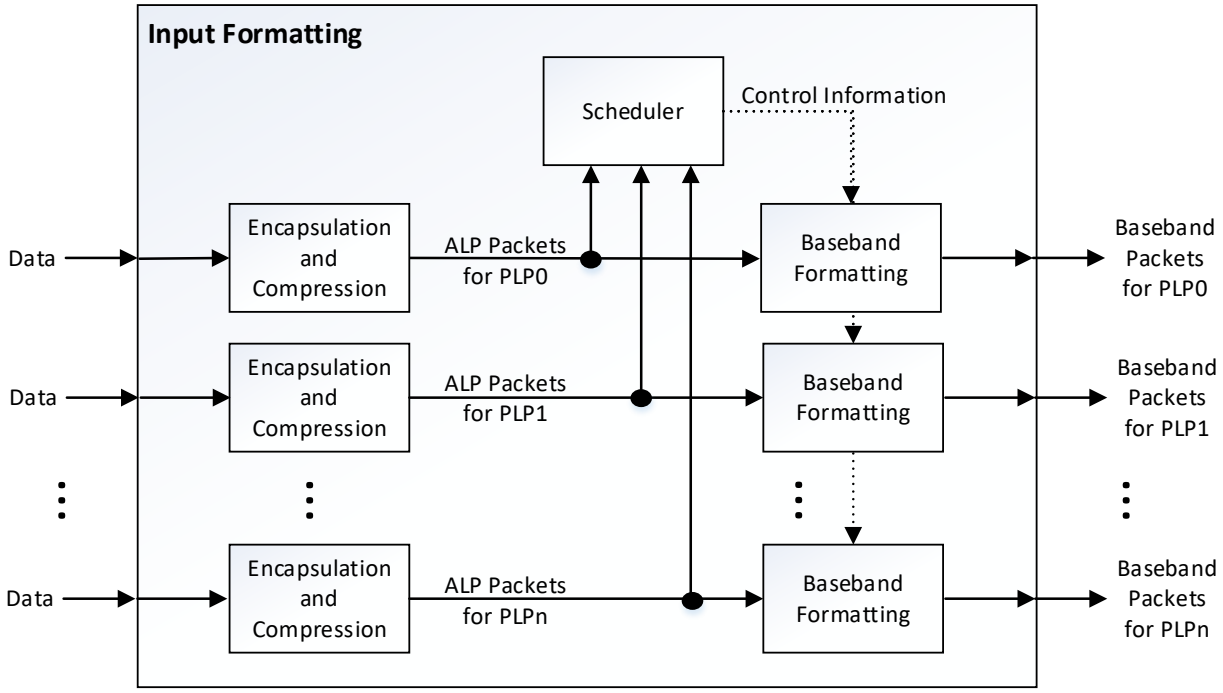


**Figure 5.1** Block diagram of input formatting.

## 5.1 Encapsulation and Compression

Input data packets shall be formatted according to the [3] specification in this block, including all necessary encapsulation and compression of the input data. The output packets are called ALP (ATSC Link-layer Protocol) packets.

The length of each ALP packet is variable and can be extracted from the ALP packet header. The maximum length of any single ALP packet, including all headers and data, shall be as defined and constrained as in [3].

### 5.1.1 Number of PLPs

The maximum number of PLPs in each RF channel (6, 7 or 8 MHz) shall be 64. The minimum number of PLPs in an RF channel shall be one. The maximum number of PLPs in a frame carrying content requiring simultaneous recovery to assemble a single delivered product shall be four, subject to the constraints described in Section 7.1.2. Note that Low Level Signaling (LLS) is one component of a delivered product.

## 5.2 Baseband Formatting

The baseband formatting block, shown in Figure 5.2, consists of three blocks, Baseband Packet Construction, Baseband Packet Header Addition and Baseband Packet Scrambling. The baseband formatting block creates one or more PLPs as directed by the Scheduler. At the output of the baseband formatting block, each PLP consists of a stream of Baseband Packets and there is exactly one Baseband Packet per defined FEC Frame.

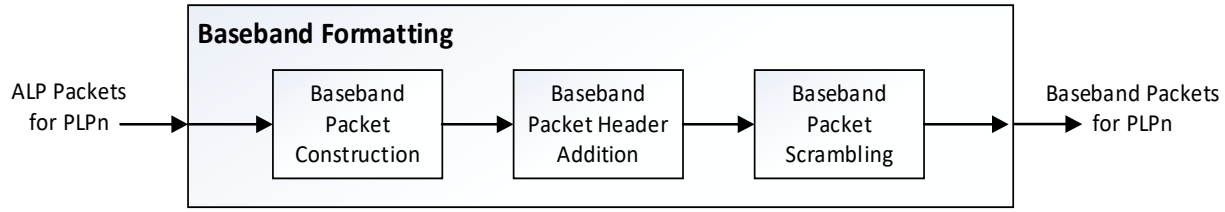


**Figure 5.2** Block diagram of baseband formatting.

The mapping operation of ALP packets to Baseband Packets is described in Section 5.2.1, the Baseband Packet Header construction is described in Section 5.2.2 and the scrambling of the entire Baseband Packet is described in Section 5.2.3.

### 5.2.1 Mapping ALP Packets to Baseband Packets

A Baseband Packet shall consist of a header, described in Section 5.2.2, and a payload containing ALP packets, shown in Figure 5.3. Padding, if present, shall be added to the Baseband Packet Header. Baseband Packets have fixed length $K_{payload}$, with the length determined by the outer code type, inner code rate and code length chosen for the target PLP. For specific values of $K_{payload}$ , see Table 6.1 and Table 6.2.

ALP packets shall be mapped to the payload part in the same order they are received. The reordering of ALP packets in the Baseband Packet is not permitted. When the received ALP packets are not sufficient to create a Baseband Packet of size $K_{payload}$, padding shall be added to the Baseband Packet Header to complete the Baseband Packet. See Section 5.2.2.3.2 for details.

When the received ALP packets are enough to fill the Baseband Packet but the last ALP packet does not fit perfectly within the Baseband Packet, that ALP packet may be split between the current Baseband Packet with the remainder of the ALP packet transmitted at the start of the next Baseband Packet. When splitting is used, ALP packets shall be split in byte units only. When the final ALP packet in the Baseband Packet is not split, padding shall be used in the extension field of the Baseband Packet Header to completely fill the Baseband Packet. In Figure 5.3 the final ALP packet is split between the current Baseband Packet and the next Baseband Packet.

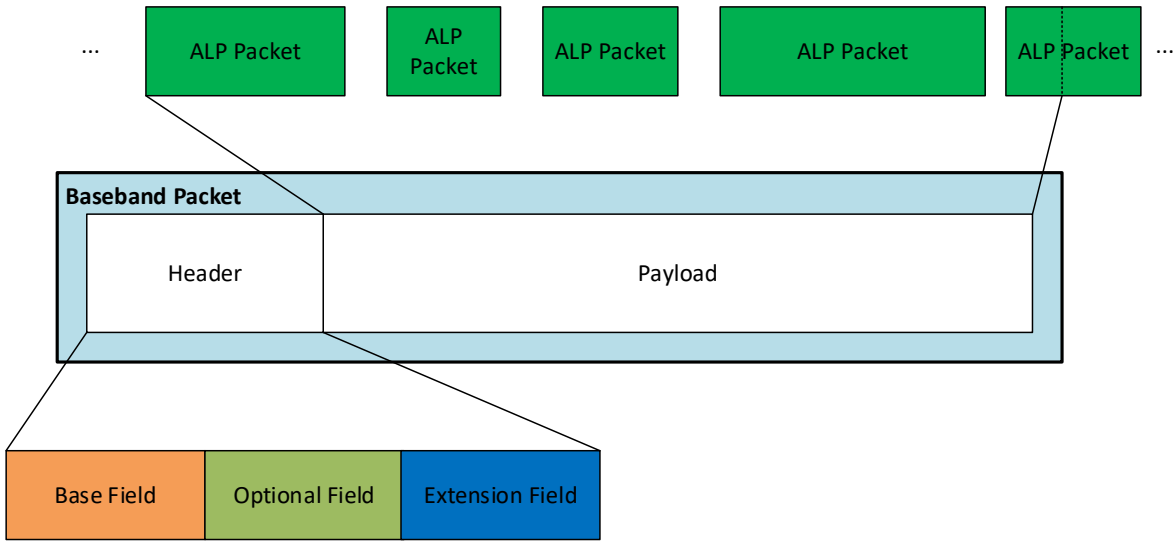


**Figure 5.3** Baseband Packet structure showing Header, Payload and mapping example of ALP packets to a Baseband Packet.

### 5.2.2 Baseband Packet Header

The Baseband Packet Header shall be composed of up to three parts, illustrated in Figure 5.3 and with more detail in Figure 5.4. The first part is called the Base Field and appears in every packet. The second part is called the Optional Field. The third part is called the Extension Field. The order of the fields shall be Base, Optional and Extension. The Optional Field may be used to provide signaling regarding the following Extension Field. When Extension Fields are used, the Optional Field shall always be present.

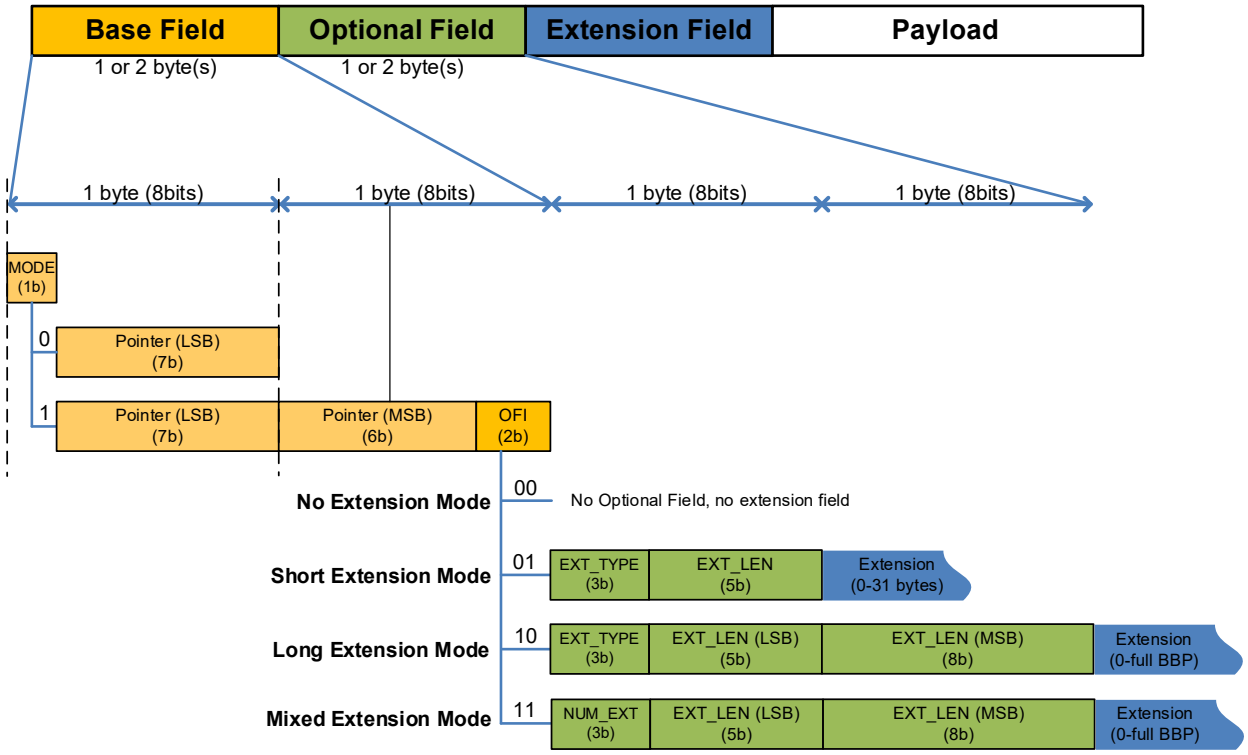


**Figure 5.4** Baseband Packet Header structure details.

#### 5.2.2.1 Base Field

Since ALP packets may be split across Baseband Packets, the start of the payload of a Baseband Packet does not necessarily signify the start of an ALP packet. The Base Field of a Baseband Packet shall provide the start position of the first ALP packet that begins in the Baseband Packet through a pointer.

The value of the pointer shall be the offset (in bytes) from the beginning of the payload to the start of the first ALP packet that begins in that Baseband Packet. When an ALP packet begins at the start of the payload portion of a Baseband Packet, the value of the pointer shall be 0. When there is no ALP packet starting within that Baseband Packet, the value of the pointer shall be 8191 and a 2 byte Base Field shall be used. When there are no ALP packets and only padding is present, the value of the pointer shall also be 8191 and a 2 byte Base Field shall be used, together with any necessary Optional Fields and Extension Fields as signaled by the OFI (Optional Field Indicator) field.

Signaling of the Base Field is as defined below:

**MODE** - This field shall indicate whether the Base Field has a length of one byte (**MODE**=0) or two bytes (**MODE**=1), and shall thus indicate the absence or presence of the upper 6 MSB bits of the pointer field and the **OFI** field.

When **MODE**=0 the pointer value shall be strictly less than 128 bytes. The pointer field length shall be 7 bits and the value of the pointer shall be transmitted in **Pointer_LSB** only. Within **Pointer_LSB** the bits shall be ordered from most significant bit to least significant bit. The length of the Base Field shall be one byte and no Optional Field and Extension Field shall be used.

When **MODE**=1 the pointer field length shall be 13 bits and the pointer field shall consist of a concatenation of the fields **Pointer_LSB** and **Pointer_MSB** in the base field. Within both **Pointer_LSB** and **Pointer_MSB** the bits shall be ordered from most significant bit to least significant bit. The length of the Base Field shall be two bytes and the use of optional and extension fields shall be allowed. Note the order of the concatenation shall be as shown in Figure 5.4, with the lowest 7 bits (LSB) concatenated with the upper 6 bits (MSB). For example, if the decimal value of the pointer is 130, **MODE**=1 and the lower 7 bits of the pointer (0000010) shall be concatenated with the upper 6 bits of the pointer (000001) to give the output of the Baseband Packet Header as 10000010 00000100, assuming **OFI**=0.

**Pointer_LSB** - This field shall be the 7 least significant bits of the pointer field.

**Pointer_MSB** - This field shall be the 6 most significant bits of the (13-bit) pointer field.

**OFI** - This field shall indicate the Baseband Packet Header extension mode, specified in Table 5.1 .

**Table 5.1** OFI Description

| OFI | Description |
|---|---|
| 00 | No Extension Mode:<br>Absence of both Optional and Extension Fields |
| 01 | Short Extension Mode:<br>Presence of the Optional Field, with length equal to 1 byte. |
| 10 | Long Extension Mode:<br>Presence of the Optional Field, with length equal to 2 bytes. |
| 11 | Mixed Extension Mode<br>Presence of the Optional Field, with length equal to 2 bytes |

#### 5.2.2.2 Optional Field

The Optional Field shall only be present when **OFI** is set to ‘01’, ‘10’ or ‘11’. When **OFI**=01 it is known as Short Extension Mode and is defined in Section 5.2.2.2.1. When **OFI** =10 it is known as Long Extension Mode and is defined in Section 5.2.2.2.3. When **OFI** =11 it is known as Mixed Extension Mode and is defined in Section 5.2.2.2.3.

##### 5.2.2.2.1 Short Extension Mode

The Extension Field shall be composed according to the **EXT_TYPE** and **EXT_LEN** fields in the Optional Field. When the actual length of the signaled extension type is shorter than what is indicated by **EXT_LEN**, padding consisting of 0x00 shall be used to fill up the missing bytes as defined in Section 5.2.2.3.2.

The following fields shall be present:

**EXT_TYPE**: This field shall indicate the type of the extension transmitted in the Extension Field, as defined in Table 5.2. Only one extension type per Baseband Packet shall be used.

**EXT_LEN**: This field shall indicate the length in bytes of the Extension Field in the range 0-31 bytes. When **EXT_LEN** =0 this implies that no Extension Field is present.

#### 5.2.2.2.2 Long Extension Mode

The Extension Field shall be composed according to the **EXT_TYPE** and **EXT_LEN (LSB)** concatenated with **EXT_LEN (MSB)** fields in the Optional Field. When the actual length of the signaled extension type is shorter than what is indicated by the concatenation of **EXT_LEN (LSB)** and **EXT_LEN (MSB)**, padding with 0x00 shall be used to fill up the missing bytes as defined in Section 5.2.2.3.2.

The following fields shall be present:

**EXT_TYPE**: This field shall indicate the type of Extension Field, as defined in Table 5.2. Only one extension type per Baseband Packet shall be used.

**EXT_LEN (LSB)**: This field shall indicate the LSB part of the 13-bit **EXT_LEN**

**EXT_LEN (MSB)**: This field shall indicate the MSB part of the 13-bit **EXT_LEN**

The concatenation **EXT_LEN** (13 bits) of the fields **EXT_LEN (LSB)** and **EXT_LEN (MSB)** in the Optional Field shall indicate the actual length in bytes of any Extension Field in the range 0 bytes to the end of the Baseband Packet. When **EXT_LEN** indicates an Extension Field of 0 bytes this implies that no Extension Field is present.

#### 5.2.2.2.3 Mixed Extension Mode

The Extension Field shall consist of N non-padding extensions (where $2 \leq N \leq 7$) as well as any padding. The structure of the Extension Field shall be as defined in Figure 5.5.

**Figure 5.5** Structure of Extension Field for the Mixed Extension Mode.

With N non-padding extensions there shall be one 2-byte header for each such extension, i.e. a total header part of the Extension Field of 2N bytes. In the Extension Field all N headers shall first be transmitted, followed by the N associated payload fields, following the same order, and finally any padding.

In each 2-byte header the first byte shall consist of a 3-bit field, **EXT_TYPE**, indicating the extension type followed by the 5-bit LSB part of the 13-bit **EXT_LEN** field of the particular extension. The second byte shall consist of the 8-bit MSB part of the same **EXT_LEN** field, which is the concatenation of the respective LSB and MSB parts. No header shall precede the padding bytes, if present, at the end of the Extension Field. The position and length of padding is implicit from other fields.

The following fields shall be present:

**NUM_EXT** (3 bits): This field shall indicate the number of non-padding extensions N ($2 \leq N \leq 7$) in the Extension Field.

**EXT_LEN (LSB)** (5 bits): This field shall indicate the LSB part of the 13-bit **EXT_LEN**

**EXT_LEN (MSB)** (8 bits): This field shall indicate the MSB part of the 13-bit **EXT_LEN**

The concatenation **EXT_LEN** (13 bits) of the fields **EXT_LEN (LSB)** and **EXT_LEN (MSB)** in the Optional Field shall indicate the actual length in bytes of the Extension Field in the range 4 bytes to end of Baseband Packet.

In the current version of the specification Extension Fields and associated **EXT_TYPE** entries shall be as defined in Table 5.2. Later specification versions may define additional extension types.

**Table 5.2 EXT_TYPE** Field Description for Extension Mode

| EXT_TYPE | Description |
|---|---|
| 000 | Counter<br>A counter as defined in Section 5.2.2.3.1 shall be used |
| 001-110 | These fields are reserved for future extension types |
| 111 | All Padding<br>All bytes of the extension field are padded with 0x00 as defined in Section 5.2.2.3.2. |

#### 5.2.2.3 Extension Fields

The Extension Field types are defined below.

##### 5.2.2.3.1 Counter Type

When **EXT_TYPE** =‘000’ an extension of length **EXT_LEN** bytes containing a counter shall be added. The counter shall be of 2 bytes in length and shall immediately follow the Optional Field. The first byte of the extension shall represent the most significant byte of the counter and the second byte of the extension shall represent the least significant byte of the counter. **EXT_LEN** shall have a minimum value of 2. Values of **EXT_LEN** > 2 shall indicate the presence of padding following the counter. Note that if a Baseband Packet with only padding needs to be sent, **EXT_TYPE** =111 shall be used and use of the counter type is unnecessary.

The counter shall be initialized to 0 and shall increment linearly by one for each Baseband Packet of the current PLP. Independent counters shall be used for each PLP. When the counter reaches its maximum value, the next Baseband Packet counter value shall be reset to zero and the counting process shall begin again.

For a PLP employing channel bonding, a single counter shall be used to add the value to the Baseband Packet (see also Section K.1). This shall occur before the Baseband Packet is assigned to the specified RF channel.

As an example, if **OFI**=‘01’ and **EXT_LEN** =‘5’, the counter will be 2 bytes in length and the remaining 3 bytes of the extension will contain padding. The length of the Base Field is 2 bytes, the length of the Optional Field is 1 byte and the length of the Extension Field is 5 bytes for a total Baseband Packet Header length of 8 bytes.

##### 5.2.2.3.2 All Padding Type

For **OFI**=01 and **OFI**=10 an Extension Field may be entirely used for padding by setting **EXT_TYPE** =‘111’ as described in Table 5.2. When one or more non-padding extensions do not entirely fill the available Extension Field the last part of the Extension Field is filled with padding bytes, which in all cases have the value 0x00. In this latter case there is no explicit padding signaling.

The use of **OFI**=‘01’ together with an **EXT_LEN** field indicating a 0-byte length of the Extension Field is equivalent to introducing 1 byte of padding, compared to the **OFI**=00 case.

The use of **OFI**=‘10’ together with an **EXT_LEN** field indicating a 0-byte length of the Extension Field is equivalent to introducing 2 bytes of padding, compared to the **OFI**=00 case.

### 5.2.3 Scrambling of Baseband Packets

In order to ensure that the data mapped to constellations is not assigned to the same point in an undesirable manner (which might occur for example when the payload consists of a repetitive sequence) the entire Baseband Packet, consisting of both the Baseband Packet Header and payload, shall always be scrambled before forward error correction encoding.

The scrambling sequence can be generated by the 16-bit shift register shown in Figure 5.6.

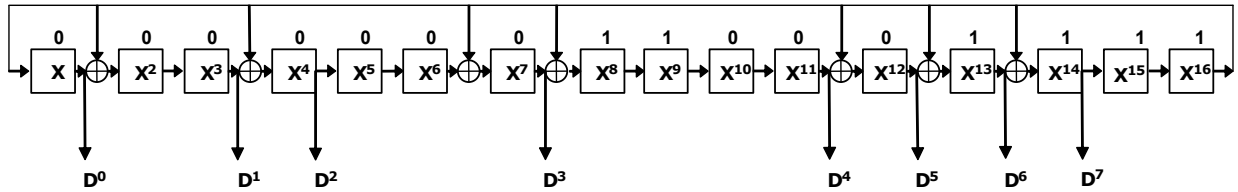


**Figure 5.6** Shift register of the PRBS encoder for baseband scrambling.

The generator polynomial shall be:

$$G(x) = 1+X+X^3+X^6+X^7+X^{11}+X^{12}+X^{13}+X^{16}$$

The operation of the scrambling sequence shall be as follows:

1) The initial sequence (0xF180: 1111 0001 1000 0000) shall be loaded into the shift register at the start of every Baseband Packet.
2) Eight of the shift register outputs ($D^7$, $D^6$, …, $D^0$) are used as a randomizing byte, which shall then be XOR'd bitwise (MSB to MSB and so on until LSB to LSB) with the corresponding byte of Baseband Packet data.
3) The bits in the shift register shall be shifted once. Go to step 2 above.

The first values of the baseband scrambling sequence are 1100 0000 0110 1101 0011 1111 … (MSB first, or $D^7$, $D^6$, …, $D^0$, $D^7$, $D^6$, …).

## 6. BIT-INTERLEAVED CODED MODULATION (BICM)

A simple block diagram of the Bit-Interleaved Coded Modulation (BICM) block is shown in Figure 6.1. The BICM block consists of three parts: The Forward Error Correction (FEC), the Bit Interleaver and the Mapper. The BICM block operates per PLP.

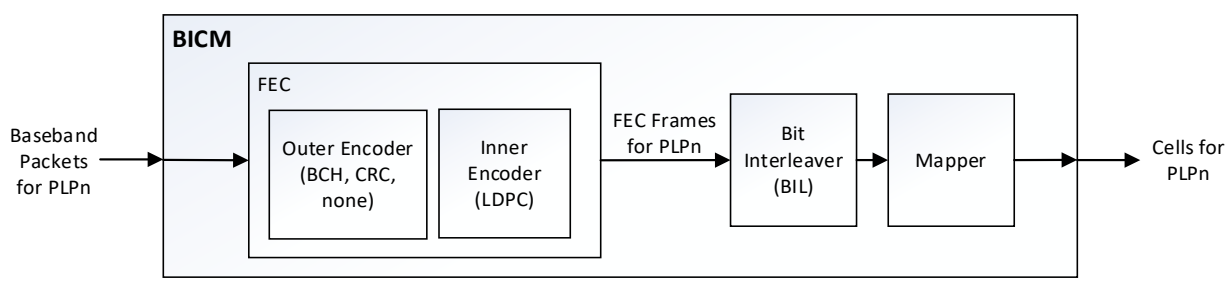


**Figure 6.1** Block diagram of BICM.

### 6.1 Forward Error Correction (FEC)

The input to the FEC part is a Baseband Packet and the output is a FEC Frame. The construction of the FEC Frame is described in Section 6.1.1, with the details of the forward error correction described in Sections 6.1.2 and 6.1.3. It should be noted that the size of the input Baseband Packet depends on the inner code rate and length and outer code type. The size of the FEC Frame depends on the code length only.

#### 6.1.1 FEC Frame Structure

A FEC Frame shall be formed by the concatenation of the Baseband Packet payload, an Outer Code and an Inner Code. The FEC Frame has size $N_{inner}$, expressed in bits, where the size comes from the length of the Inner Code.

The Inner Code shall be a Low Density Parity Check (LDPC) code. There are two different sizes of LDPC code defined: $N_{inner}$ =64800 bits and $N_{inner}$ =16200 bits. The use of one of the defined Inner Codes is mandatory and is used to provide the redundancy needed for correct reception of transmitted Baseband Packets. The length of the Inner Code parity $M_{inner}$ depends on the code rate as well as $N_{inner}$. The choice of Inner Code type is signaled together with the Outer Code type using the **L1D_plp_fec_type** field.

There are three options for the Outer Code: Bose, Ray-Chaudhuri and Hocquenghem (BCH) Outer Code, a Cyclic Redundancy Check (CRC) or none. The Outer Code (BCH and CRC) adds $M_{outer}$ parity bits to the input Baseband Packet. When using BCH codes the length of $M_{outer}$ shall be 192 bits (for $N_{inner}$=64800 bit codes) and 168 bits (for $N_{inner}$=16200 bit codes), respectively. When using CRC the length of $M_{outer}$ shall be 32 bits. The resulting structure of the concatenation of the payload, BCH or CRC parities and LDPC parities is defined as shown in Figure 6.2.

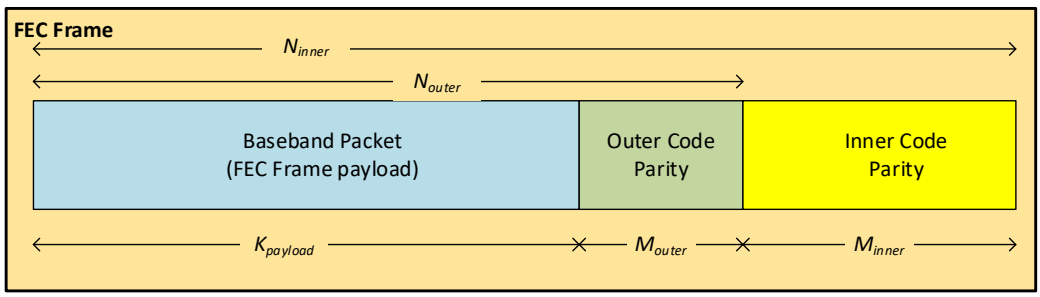


**Figure 6.2** Structure of FEC Frame when BCH or CRC is used as Outer Code.

When neither BCH nor CRC is used the length of $M_{outer}$ is zero, and the structure of the FEC Frame is as shown in Figure 6.3.

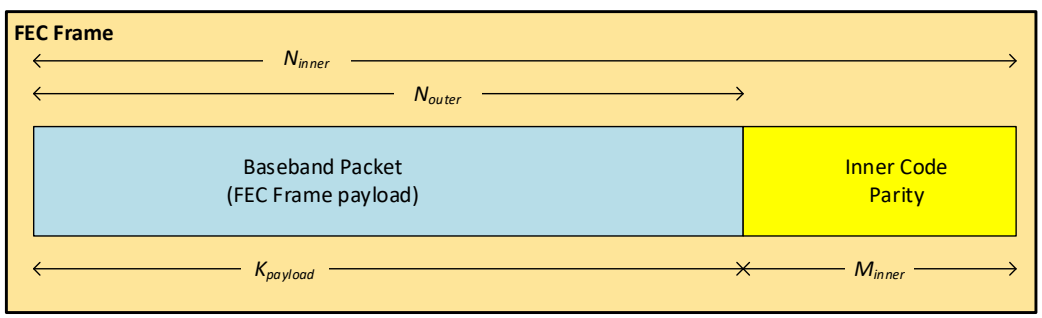


**Figure 6.3** Structure of FEC Frame when no Outer Code is used.

The size of $K_{payload}$ therefore, depends on the type of Outer Code used in addition to the code rate and Inner Code length. The size of $K_{payload,}$ as well as $M_{outer}$, $M_{inner}$ and $N_{outer}$ are shown in Table 6.1 and Table 6.2.

**Table 6.1** Length of $K_{payload}$ (bits) for $N_{inner}$ = 64800

| Code Rate | $K_{payload}$ (BCH) | $M_{outer}$ (BCH) | $K_{payload}$ (CRC) | $M_{outer}$ (CRC) | $K_{payload}$ (no outer) | $M_{outer}$ (no outer) | $M_{inner}$ | $N_{outer}$ |
|---|---|---|---|---|---|---|---|---|
| 2/15 | 8448 | 192 | 8608 | 32 | 8640 | 0 | 56160 | 8640 |
| 3/15 | 12768 | 192 | 12928 | 32 | 12960 | 0 | 51840 | 12960 |
| 4/15 | 17088 | 192 | 17248 | 32 | 17280 | 0 | 47520 | 17280 |
| 5/15 | 21408 | 192 | 21568 | 32 | 21600 | 0 | 43200 | 21600 |
| 6/15 | 25728 | 192 | 25888 | 32 | 25920 | 0 | 38880 | 25920 |
| 7/15 | 30048 | 192 | 30208 | 32 | 30240 | 0 | 34560 | 30240 |
| 8/15 | 34368 | 192 | 34528 | 32 | 34560 | 0 | 30240 | 34560 |
| 9/15 | 38688 | 192 | 38848 | 32 | 38880 | 0 | 25920 | 38880 |
| 10/15 | 43008 | 192 | 43168 | 32 | 43200 | 0 | 21600 | 43200 |
| 11/15 | 47328 | 192 | 47488 | 32 | 47520 | 0 | 17280 | 47520 |
| 12/15 | 51648 | 192 | 51808 | 32 | 51840 | 0 | 12960 | 51840 |
| 13/15 | 55968 | 192 | 56128 | 32 | 56160 | 0 | 8640 | 56160 |

**Table 6.2** Length of $K_{payload}$ (bits) for $N_{inner}$ = 16200

| Code Rate | $K_{payload}$ (BCH) | $M_{outer}$ (BCH) | $K_{payload}$ (CRC) | $M_{outer}$ (CRC) | $K_{payload}$ (no outer) | $M_{outer}$ (no outer) | $M_{inner}$ | $N_{outer}$ |
|---|---|---|---|---|---|---|---|---|
| 2/15 | 1992 | 168 | 2128 | 32 | 2160 | 0 | 14040 | 2160 |
| 3/15 | 3072 | 168 | 3208 | 32 | 3240 | 0 | 12960 | 3240 |
| 4/15 | 4152 | 168 | 4288 | 32 | 4320 | 0 | 11880 | 4320 |
| 5/15 | 5232 | 168 | 5368 | 32 | 5400 | 0 | 10800 | 5400 |
| 6/15 | 6312 | 168 | 6448 | 32 | 6480 | 0 | 9720 | 6480 |
| 7/15 | 7392 | 168 | 7528 | 32 | 7560 | 0 | 8640 | 7560 |
| 8/15 | 8472 | 168 | 8608 | 32 | 8640 | 0 | 7560 | 8640 |
| 9/15 | 9552 | 168 | 9688 | 32 | 9720 | 0 | 6480 | 9720 |
| 10/15 | 10632 | 168 | 10768 | 32 | 10800 | 0 | 5400 | 10800 |
| 11/15 | 11712 | 168 | 11848 | 32 | 11880 | 0 | 4320 | 11880 |
| 12/15 | 12792 | 168 | 12928 | 32 | 12960 | 0 | 3240 | 12960 |
| 13/15 | 13872 | 168 | 14008 | 32 | 14040 | 0 | 2160 | 14040 |

### 6.1.2 Outer Encoding

There are multiple choices for the Outer Code. The first is the BCH code and it provides additional error correction as well as error detection. The second is the use of a CRC, which provides no additional error correction, only error detection. As a third option, no Outer Code may be selected.

#### 6.1.2.1 BCH

When BCH is used for the Outer Code, 12-bit correctable BCH codes are used. These are determined as follows:

Let $m(x) = m_0x^{Kpayload-1}+m_1x^{Kpayload-2}+\ldots+m_{Kpayload-1}$ be an information polynomial, whose coefficients $m_0$, $m_1$, …, $m_{Kpayload-1}$ are information to be encoded, and let g(x) be the generator polynomial of degree $M_{outer}$ for BCH code where $g(x) = g_1(x)g_2(x)\ldots g_{12}(x)$. Then code bits $s_0$, $s_1$, …, $s_{Nouter-1}$ shall be induced as coefficients of a codeword polynomial of degree $N_{outer}$-1, $s(x) = s_0x^{Nouter-1}+s_1x^{Nouter-2}+\ldots+s_{Nouter-1} = m(x)x^{Mouter} - p(x)$, where p(x) is the residue polynomial of $m(x)x^{Mouter}/g(x)$. The definitions of component polynomials $g_i(x)$ for each mode are shown in Table 6.3.

**Table 6.3** BCH Polynomials

| | Code Length $N_{inner}$=64800 | Code Length $N_{inner}$=16200 |
|---|---|---|
| $g_1(x)$ | $x^{16}+x^5+x^3+x^2+1$ | $x^{14}+x^5+x^3+x+1$ |
| $g_2(x)$ | $x^{16}+x^8+x^6+x^5+x^4+x+1$ | $x^{14}+x^{11}+x^8+x^6+1$ |
| $g_3(x)$ | $x^{16}+x^{11}+x^{10}+x^9+x^8+x^7+x^5+x^4+x^3+x^2+1$ | $x^{14}+x^{10}+x^9+x^6+x^2+x+1$ |
| $g_4(x)$ | $x^{16}+x^{14}+x^{12}+x^{11}+x^9+x^6+x^4+x^2+1$ | $x^{14}+x^{12}+x^{10}+x^8+x^7+x^4+1$ |
| $g_5(x)$ | $x^{16}+x^{12}+x^{11}+x^{10}+x^9+x^8+x^5+x^3+x^2+x+1$ | $x^{14}+x^{13}+x^{11}+x^9+x^8+x^6+x^4+x^2+1$ |
| $g_6(x)$ | $x^{16}+x^{15}+x^{14}+x^{13}+x^{12}+x^{10}+x^9+x^8+x^7+x^5+x^4+x^2+1$ | $x^{14}+x^{13}+x^9+x^8+x^7+x^3+1$ |
| $g_7(x)$ | $x^{16}+x^{15}+x^{13}+x^{11}+x^{10}+x^9+x^8+x^6+x^5+x^2+1$ | $x^{14}+x^{13}+x^{11}+x^{10}+x^7+x^6+x^5+x^2+1$ |
| $g_8(x)$ | $x^{16}+x^{14}+x^{13}+x^{12}+x^9+x^8+x^6+x^5+x^2+x+1$ | $x^{14}+x^{11}+x^{10}+x^9+x^8+x^5+1$ |
| $g_9(x)$ | $x^{16}+x^{11}+x^{10}+x^9+x^7+x^5+1$ | $x^{14}+x^{10}+x^9+x^3+x^2+x+1$ |
| $g_{10}(x)$ | $x^{16}+x^{14}+x^{13}+x^{12}+x^{10}+x^8+x^7+x^5+x^2+x+1$ | $x^{14}+x^{12}+x^{11}+x^9+x^6+x^3+1$ |
| $g_{11}(x)$ | $x^{16}+x^{13}+x^{12}+x^{11}+x^9+x^5+x^3+x^2+1$ | $x^{14}+x^{12}+x^{11}+x^4+1$ |
| $g_{12}(x)$ | $x^{16}+x^{12}+x^{11}+x^9+x^7+x^6+x^5+x+1$ | $x^{14}+x^{13}+x^{10}+x^8+x^7+x^6+x^5+x^3+x^2+x+1$ |

6.1.2.2 CRC

When a CRC is used for the Outer Code, a 32-bit CRC shall be used. The CRC shall be computed as illustrated in Figure 6.4 and shall implement a feedback shift register characterized by the CRC code polynomial. The generator polynomial of degree $n$ $G_{crc}(x)$ can be expressed as:

$$G_{crc}(x) = x^n + g_{n-1}x^{n-1} + g_{n-2}x^{n-2} + ..... + g_2x^2 + g_1x + 1$$

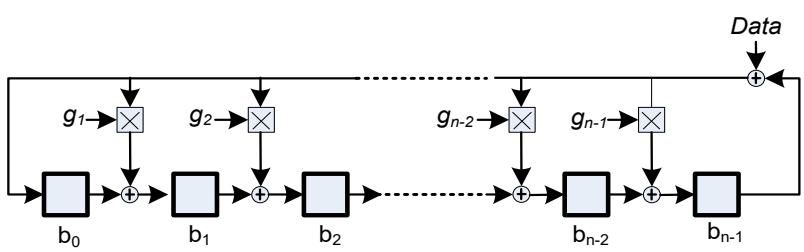


**Figure 6.4** Shift register for CRC-32.

Computation of the CRC-32 can be carried out using a shift register circuit such as shown in Figure 6.4. At the beginning of the computation (before the first data bit is input) all register stage contents shall be initialized to one. After applying the first bit (MSB first) of the data block to the input, the shift clock causes the register to shift its contents by one stage towards $b_{n-1}$ while loading the tapped stages with the result of the appropriate operations. After the last data bit of the block is input, the contents of the register stages are read out to provide the 32 CRC bits $\{b_i, i = 0,1\ldots31)$ that shall then be appended to the data prior to inner encoding. The appended bits shall be ordered from the most significant bit ($b_{31}$) to the least significant bit ($b_0$). For the CRC-32 used, all values of $g_i = 0$ except for: $g_{21}$ , $g_{16}$, $g_{11}$ which shall have a value of one. Thus the actual generator polynomial shall be:

$$G_{crc}(x) = x^{32} + x^{21} + x^{16} + x^{11} + 1$$

#### 6.1.2.3 Selection of Outer Code Configuration

The BCH Outer Code is used to lower any potential LDPC error floor by correcting a predefined number of bit errors. For the BCH codes chosen up to 12 bit errors may be corrected. BCH code provides both improved error correction as well as error detection. For improved efficiency, at the cost of no additional error correction, the CRC may be chosen. CRC provides only error detection. Finally, the Outer Code may be omitted if it is determined that the error correcting capability of the Inner Code is sufficient for the application; however, no additional error correction or detection is provided in this case.

### 6.1.3 Inner Encoding

LDPC codes are used to create parity bits which are appended to the payload in each Baseband Packet. Cyclic-structured LDPC codes are employed. The indices list for each encoding can be found in Annex A.

There are two different coding structures used. These are called Type A (defined in Section 6.1.3.1) and Type B (defined in Section 6.1.3.2). The type used for each code rate and code length shall be as shown in Table 6.4. Type A has a code structure that shows better performance at low code rates while Type B code structure shows better performance at high code rates.

**Table 6.4** Structure of LDPC Encoding Used for Each of the Code Rates and Lengths

| Code Rate | LDPC Code Structure Type | |
|---|---|---|
| | $N_{inner}$=64800 | $N_{inner}$=16200 |
| 2/15 | A | A |
| 3/15 | A | A |
| 4/15 | A | A |
| 5/15 | A | A |
| 6/15 | B | B |
| 7/15 | A | B |
| 8/15 | B | B |
| 9/15 | B | B |
| 10/15 | B | B |
| 11/15 | B | B |
| 12/15 | B | B |
| 13/15 | B | B |

#### 6.1.3.1 Type A LDPC Encoding

Type A LDPC encoding shall be realized as follows.

An LDPC code is used to encode the information block $S = (s_0, s_1, \dots, s_{N_{outer}-1})$. To generate a codeword $\Lambda = (\lambda_0, \lambda_1, \dots, \lambda_{N_{inner}-1})$ of length $N_{inner} = N_{outer} + M_1 + M_2$, the parity bits before parity interleaving $P = (p_0, p_1, \dots, p_{M_1+M_2-1})$ are calculated from S. Then for any $i$ from 0 to $N_{outer} - 1$, $\lambda_i$ is set equal to $s_i$, since the code is systematic.

$M_1$ and $M_2$ are parity lengths corresponding to a dual diagonal matrix and an identity matrix, respectively. The parity lengths depending on code rates shall be used as specified in Table 6.5 and Table 6.6. The detailed procedure to calculate parity bits shall be as follows:

i) Initialize $\lambda_i = s_i$ for $i = 0,1, \dots N_{outer} - 1$

$$p_j = 0 \text{ for } j = 0,1,\ldots M_1 + M_2 - 1$$

Accumulate the first information bit, $\lambda_0$, at parity bit addresses specified in the first row of the tables in Annex A (Table A.1.1 to Table A.1.4, Table A.1.6, Table A.2.1 to Table A.2.4).

ii) For the next 359 information bits $\lambda_m, m = 1,2,\ldots,359$, accumulate $\lambda_m$ at parity bit addresses, which are calculated as follows:

$$(x + m \times Q_1) \bmod M_1 \qquad \text{if } x < M_1$$

$$M_1 + \{(x - M_1 + m \times Q_2)\} \bmod M_2 \qquad \text{if } x \geq M_1$$

where $x$ denotes the address of the parity bit accumulator corresponding to the first bit $\lambda_0$. $Q_1 = M_1/360$ and $Q_2 = M_2/360$ are code rate dependent constants specified in Table 6.5 and Table 6.6.

iii) For the 361st information bit $\lambda_{360}$, the addresses of the parity bit accumulators are given in the second row of the tables in Annex A. In a similar manner, the addresses of the parity bit accumulators for the following 359 information bits $\lambda_m,\ m = 361,362,\ldots,719$ are obtained using the equation in step (ii) where $x$ denotes the address of the parity bit accumulator corresponding to the information bit $\lambda_{360}$, i.e. the entries in the second row of the tables in Annex A.

iv) In a similar manner, for every group of 360 new information bits, a new row from the tables in Annex A is used to find the addresses of the parity bit accumulators.

v) After the codeword bits from $\lambda_0$ to $\lambda_{N_{outer}-1}$ are exhausted, sequentially perform the following operations starting with $i = 1$.

$$p_i = p_i \oplus p_{i-1} \text{ for } i = 1,2,\ldots,M_1 - 1$$

vi) The parity bits from $\lambda_{N_{outer}}$ to $\lambda_{N_{outer}+M_1-1}$, which correspond to the dual diagonal matrix, are obtained using the following interleaving operation:

$$\lambda_{N_{outer}+360\ \cdot\ t+s} = p_{Q_1 \cdot\ s+t} \text{ for } 0 \leq s < 360, 0 \leq t < Q_1$$

vii) For every group of 360 new codeword bits from $\lambda_{N_{outer}}$ to $\lambda_{N_{outer}+M_1-1}$, a new row from the tables in Annex A and the equation in step (ii) are used to find the addresses of the parity bit accumulators.

viii) After the codeword bits from $\lambda_{N_{outer}}$ to $\lambda_{N_{outer}+M_1-1}$ are exhausted, the parity bits from $\lambda_{N_{outer}+M_1}$ to $\lambda_{N_{outer}+M_1+M_2-1}$, which correspond to the identity matrix, are obtained using the following interleaving operation:

$$\lambda_{N_{outer}+M_1+360\ \cdot\ t+s} = p_{M_1+Q_2 \cdot\ s+t} \text{ for } 0 \leq s < 360, 0 \leq t < Q_2$$

Note that the parity bits from $\lambda_{N_{outer}}$ to $\lambda_{N_{outer}+M_1-1}$ are obtained according to steps (i) to (vi), and then the parity bits from $\lambda_{N_{outer}+M_1}$ to $\lambda_{N_{outer}+M_1+M_2-1}$ are obtained using the results of steps (i) to (vi) according to steps (vii) to (viii).

**Table 6.5** Coding Parameters for Type A: $N_{inner}$ = 64800

| Code Rate | Sizes | | | |
|---|---|---|---|---|
| | $M_1$ | $M_2$ | $Q_1$ | $Q_2$ |
| 2/15 | 1800 | 54360 | 5 | 151 |
| 3/15 | 1800 | 50040 | 5 | 139 |
| 4/15 | 1800 | 45720 | 5 | 127 |
| 5/15 | 1440 | 41760 | 4 | 116 |
| 7/15 | 1080 | 33480 | 3 | 93 |

**Table 6.6** Coding Parameters for Type A: $N_{inner}$ = 16200

| Code Rate | Sizes | | | |
|---|---|---|---|---|
| | $M_1$ | $M_2$ | $Q_1$ | $Q_2$ |
| 2/15 | 3240 | 10800 | 9 | 30 |
| 3/15 | 1080 | 11880 | 3 | 33 |
| 4/15 | 1080 | 10800 | 3 | 30 |
| 5/15 | 720 | 10080 | 2 | 28 |

#### 6.1.3.2 Type B LDPC Encoding

Type B LDPC encoding shall be realized as follows.

Let $s_0, s_1, \ldots, s_{Nouter-1}$ be information bits to be encoded and $\lambda_0, \lambda_1, \ldots, \lambda_{Ninner-1}$ be code bits to be calculated. Then for any $k$ from 0 to $N_{outer}$-1, $\lambda_k$ shall be set equal to $s_k$, since the code is systematic. For the remaining code bits, set $\lambda_{Nouter+k} = p_k$ ($0 \le k < M_{inner}$) and these parity bits $p_k$ shall be calculated as follows. In the following, q(i, j, 0) denotes the j-th entry in the i-th row in the indices list, see Annex A, and q(i, j, $l$) = q(i, j, 0) + $Q_{ldpc} \cdot l$ (mod $M_{inner}$) for $0<l<360$, and all accumulations are realized by additions in GF(2). $Q_{ldpc}$ shall be defined as in Table 6.7.

i) Initialize $p_k = 0$ for $0 \le k < M_{inner}$.

ii) For $0 \le k < N_{outer}$, set $i = \lfloor k/360 \rfloor$, and $l$ = k (mod 360). Now accumulate $s_k$ to $p_{q(i, j, l)}$ for all j:
$p_{q(i, 0, l)} = p_{q(i, 0, l)} + s_k$, $p_{q(i, 1, l)} = p_{q(i, 1, l)} + s_k$, $p_{q(i, 2, l)} = p_{q(i, 2, l)} + s_k, \ldots$, $p_{q(i, w(i)-1, l)} = p_{q(i, w(i)-1, l)} + s_k$,
where w(i) is the number of elements in the $i$-th row in the indices list in Annex A.

iii) For all $0 < k < M_{inner}$, $p_k = p_k + p_{k-1}$.

From these steps, all code bits $\lambda_0, \lambda_1, \ldots, \lambda_{Ninner-1}$ shall be obtained.

**Table 6.7** Coding Parameters for Type B

| Code Rate | $Q_{ldpc}$ ($N_{inner}$=64800) | $Q_{ldpc}$ ($N_{inner}$=16200) |
|---|---|---|
| 6/15 | 108 | 27 |
| 7/15 | *N/A* | 24 |
| 8/15 | 84 | 21 |
| 9/15 | 72 | 18 |
| 10/15 | 60 | 15 |
| 11/15 | 48 | 12 |
| 12/15 | 36 | 9 |
| 13/15 | 24 | 6 |

#### 6.1.3.3 Tradeoffs

$N_{inner}$ = 16200 bit LDPC codes have lower latency but worse performance. In general, $N_{inner}$ = 64800 bit codes are expected to be the first choice due to superior performance, however, for applications where latency is critical, or a simpler encoder / decoder structure is preferred, $N_{inner}$ = 16200 bit LDPC codes should be used.

## 6.2 Bit Interleavers

The bit interleaver block takes a FEC Frame as input. The output of the bit interleaver block is a bit-interleaved FEC Frame. The size of the FEC Frame does not change after the bit interleaving operation.

The bit interleaver block consists of a parity interleaver followed by a group-wise interleaver followed by a Block Interleaver. A block diagram giving the bit interleaver internal structure is shown in Figure 6.5.

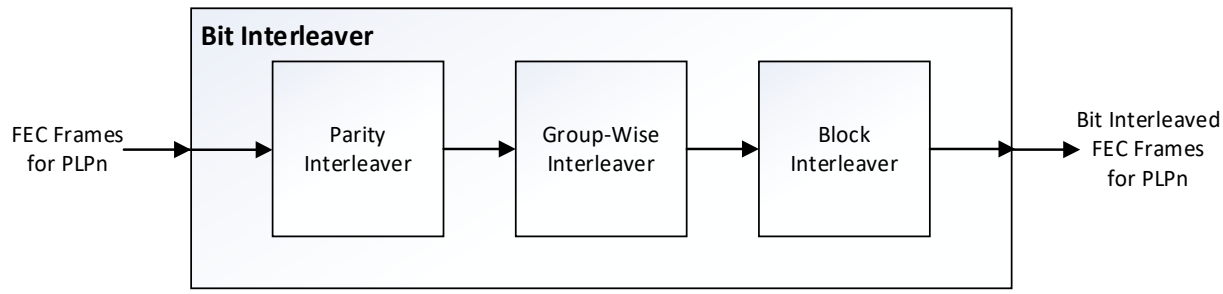


**Figure 6.5** Bit interleaver structure.

The parity interleaver is described in Section 6.2.1, the group-wise interleaver in Section 6.2.2 and the Block Interleaver in Section 6.2.3, respectively.

### 6.2.1 Parity Interleaver

The parity interleaver shall be used for Type B codes only, and shall not be used for Type A codes.

The parity interleaver output is denoted by $U = (u_0, u_1, \ldots, u_{Ninner-1})$. In the parity interleaver, parity bits shall be interleaved as:

$$u_i = \lambda_i \quad \text{for } 0 \le i < N_{outer} \text{ (information bits are not interleaved)}$$

$$u_{N_{outer}+360t+s} = \lambda_{N_{outer}+Q_{ldpc}s+t} \quad \text{for } 0 \le s < 360, 0 \le t < Q_{ldpc}$$

where $Q_{ldpc}$ is defined in Table 6.7.

The role of the parity interleaver is to convert the staircase structure of the parity-part of the LDPC parity-check matrix into a quasi-cyclic structure similar to the information-part of the matrix.

### 6.2.2 Group-Wise Interleaver

The parity interleaved LDPC coded bits, $(u_0, u_1, \ldots, u_{Ninner-1})$, shall be split into $N_{\text{group}} = N_{inner}/360$ bit groups as follows:

$$X_j = \{u_k | 360 \times j \le k < 360 \times (j+1), 0 \le k < N_{inner}\} \quad 0 \le j < N_{\text{group}}$$

where $X_j$ represents the $j$-th bit group. For $0 \le j < N_{\text{group}}$, each bit group $X_j$ has 360 bits, as illustrated in Figure 6.6.

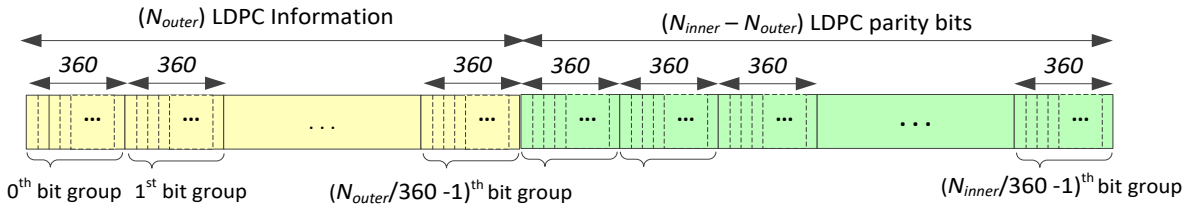


**Figure 6.6** Parity interleaved LDPC codeword bit groups.

The parity-interleaved LDPC codeword shall be interleaved by the group-wise interleaver as follows:

$$Y_j = X_{\pi(j)} \text{ for } 0 \le j < N_{group}$$

where $Y_j$ represents the group-wise interleaved $j$-th bit group and $\pi(j)$ denotes the permutation order for group-wise interleaving. The corresponding group-wise interleaving is optimized for each combination of modulation and LDPC code rate. Table series in B.1 and B.2 in Annex B show the permutation order of the group-wise interleaving $\pi(j)$ for code lengths $N_{inner} = 64800$ and $N_{inner} = 16200$, respectively.

The group-wise interleaved LDPC codeword denoted by ($v_0$, $v_1$, …, $v_{N\text{inner-1}}$) is the concatenation of $Y_j$ as follows:

$$V = \left\{Y_0, Y_1, \cdots, Y_{N_{group}-1}\right\}$$

### 6.2.3 Block Interleavers

There are Type A and Type B Block Interleavers for each Type A and Type B FEC and constellation combination. Note that some Type A FEC and constellation combinations use a Type A Block Interleaver while other Type A FEC and constellation combinations use a Type B Block Interleaver, and similarly for Type B FEC and constellation combinations and Type A and Type B Block Interleavers. That is, Type A FEC and constellation combinations are not necessarily always paired with a Type A Block Interleaver, and Type B FEC and constellation combinations are not necessarily always paired with a Type B Block Interleaver. The Block Interleaver type shall be as defined in Table 6.8 and Table 6.9. Type A Block Interleaver is described in Section 6.2.3.1 and Type B Block Interleaver is described in Section 6.2.3.2.

**Table 6.8** Block Interleaver Type for Codes of Length $N_{inner}$= 64800 Bits

| MOD \ CR | 2/15 | 3/15 | 4/15 | 5/15 | 6/15 | 7/15 | 8/15 | 9/15 | 10/15 | 11/15 | 12/15 | 13/15 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **2** | A | A | A | A | A | A | A | A | A | A | A | A |
| **4** | A | A | A | B | A | A | B | B | A | A | A | A |
| **6** | A | A | A | A | A | B | A | B | B | A | A | B |
| **8** | A | A | A | B | B | B | B | A | B | B | A | B |
| **10** | A | A | A | B | A | B | A | B | B | B | A | A |
| **12** | A | A | A | A | A | B | A | A | A | A | A | A |

**Table 6.9** Block Interleaver Type for Codes of Length $N_{inner}$= 16200 Bits

| MOD \ CR | 2/15 | 3/15 | 4/15 | 5/15 | 6/15 | 7/15 | 8/15 | 9/15 | 10/15 | 11/15 | 12/15 | 13/15 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **2** | A | A | A | A | B | B | A | B | A | A | A | A |
| **4** | A | A | A | A | B | B | A | B | A | B | A | B |
| **6** | A | A | A | A | B | B | A | B | A | A | A | A |
| **8** | A | A | A | A | B | A | A | A | A | B | A | A |

#### 6.2.3.1 Type A Block Interleaver

Following the group-wise interleaver, the LDPC codeword shall be interleaved by the Block Interleaver as shown in Figure 6.7. Each column of the Type A Block Interleaver shall be composed of a first part and a second part. Part 1 and Part 2 are divided based on the number of columns of the Block Interleaver and the number of bits of the bit group. In Part 1, the bits constituting the bit group shall be written in the same column. In Part 2, the bits constituting the bit group shall be written in at least two columns.

The data bits $v_i$ from the group-wise interleaver shall be written serially into the Block Interleaver column-wise starting in Part 1 and continuing column-wise finishing in Part 2, and shall then be read out serially row-wise from Part 1 and then row-wise from Part 2, as shown in Figure 6.7. Therefore, the bits from the same group in Part 1 shall be mapped onto the bits having the same bit position in each modulation symbol.

Part 1 and Part 2 block interleaving configurations for each modulation format and code length shall be as specified in Table 6.10. The number of columns of the Block Interleaver is equal to the number of bits constituting a modulation symbol. The sum of $N_{r1}$ and $N_{r2}$ is equal to $N_{inner}/N_c$, and $N_{r1}$ (=$\lfloor N_{group}/N_c \rfloor \times 360$) is a multiple of 360, so that multiple bit groups are written into Part 1 of Block Interleaver.

**Table 6.10** Type A Block Interleaver Configurations

| Modulation | Rows in Part 1 $N_{r1}$ | | Rows in Part 2 $N_{r2}$ | | Columns $N_c$ |
|---|---|---|---|---|---|
| | $N_{inner}$ = 64800 | $N_{inner}$ = 16200 | $N_{inner}$ = 64800 | $N_{inner}$ = 16200 | |
| QPSK | 32400 | 7920 | 0 | 180 | 2 |
| 16QAM | 16200 | 3960 | 0 | 90 | 4 |
| 64QAM | 10800 | 2520 | 0 | 180 | 6 |
| 256QAM | 7920 | 1800 | 180 | 225 | 8 |
| 1024QAM | 6480 | N/A | 0 | N/A | 10 |
| 4096QAM | 5400 | N/A | 0 | N/A | 12 |

The Block Interleaver is described as follows:

The input bit $v_i$ with index $i$, for $0 \leq i < N_c \times N_{r1}$, shall be written to column $c_i$, row $r_i$ of Part 1 in the interleaver, where:

$$c_i = \left\lfloor \frac{i}{N_{r1}} \right\rfloor$$

$$r_i = (i \bmod N_{r1})$$

and then the input bit $v$i with index $i$, for $N_c \times N_{r1} \leq i < N_{inner}$, shall be written to column $c$i, row $r$i of Part 2 in the interleaver, where:

$$c_i = \left\lfloor \frac{(i - N_c \times N_{r1})}{N_{r2}} \right\rfloor$$

$$r_i = N_{r_1} + \{(i - N_c \times N_{r1}) \bmod N_{r2}\}$$

The output bit $q_j$ with index $j$, for $0 \leq j < N_{inner}$, shall be read from row $r_j$, column $c_j$, where:

$$r_j = \left\lfloor \frac{j}{N_c} \right\rfloor$$

$$c_j = (j \bmod N_c)$$

As an example, for 256QAM and $N_{inner}$ = 64800, the output bit order of block interleaving would be:

$$(q_0, q_1, q_2, \cdots, q_{63357}, q_{63358}, q_{63359}, q_{63360}, q_{63361}, \cdots, q_{64799}) = (v_0, v_{7920}, v_{15840}, \cdots, v_{47519}, v_{55439}, v_{63359}, v_{63360}, v_{63540}, \cdots, v_{64799}).$$

A longer list of the indices on the right hand side, illustrating all 8 columns, is: 0, 7920, 15840, 23760, 31680, 39600, 47520, 55440, 1, 7921, 15841, 23761, 31681, 39601, 47521, 55441, …… , 7919, 15839, 23759, 31679, 39599, 47519, 55439, 63359, 63360, 63540, 63720, 63900, 64080, 64260, 64440, 64620, …… , 63539, 63719, 63899, 64079, 64259, 64439, 64619, 64799.

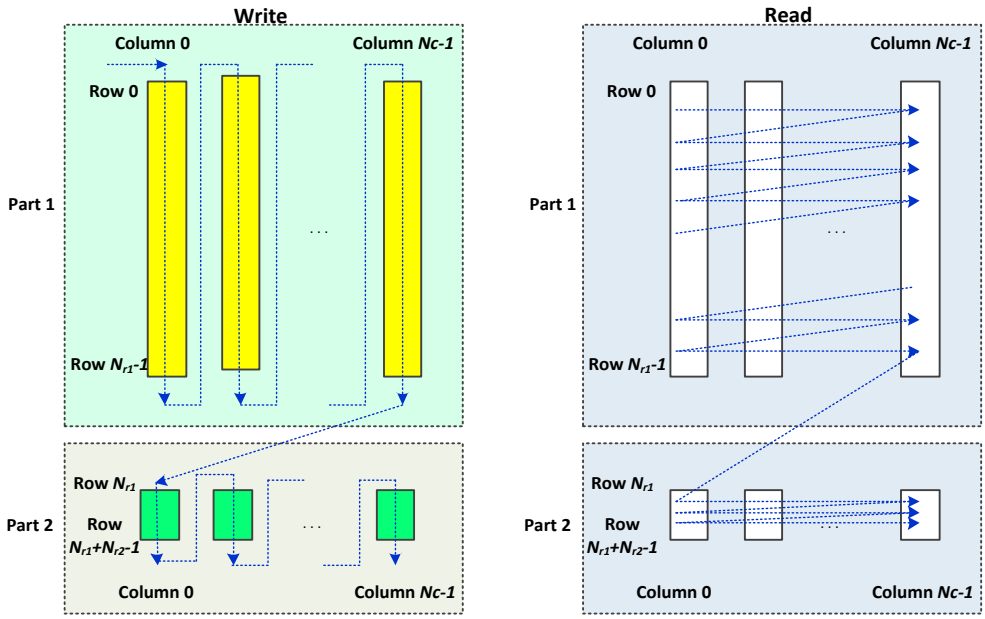


**Figure 6.7** Write/Read operation of Type A block interleaving.

#### 6.2.3.2 Type B Block Interleaver

After the group-wise interleaving, Type B block interleaving shall be performed using the parameter $N_{QCB_IG}$ which is defined according to modulation order as shown in Table 6.11. Type B block interleaving consists of Part 1 and Part 2 processes. $N_{part1}$ and $N_{part2}$ refer to the number of bits processed in Part 1 and Part 2, respectively.

**Table 6.11** Parameters for Type B Block Interleaver

| **Modulation** | $N_{QCB_IG}$ | $N_{part1}$ | | $N_{part2}$ | |
|---|---|---|---|---|---|
| | | $N_{inner}$ = 64800 | $N_{inner}$ = 16200 | $N_{inner}$ = 64800 | $N_{inner}$ = 16200 |
| QPSK | 2 | 64800 | 15840 | 0 | 360 |
| 16QAM | 4 | 64800 | 15840 | 0 | 360 |
| 64QAM | 6 | 64800 | 15120 | 0 | 1080 |
| 256QAM | 8 | 63360 | 14400 | 1440 | 1800 |
| 1024QAM | 10 | 64800 | N/A | 0 | N/A |
| 4096QAM | 12 | 64800 | N/A | 0 | N/A |

For Part 1, the Type B block interleaving process shall be performed with each set of $N_{QCB_IG}$ bit groups of the group-wise interleaver output. Part 1 process shall consist of writing and reading the bits of the $N_{QCB_IG}$ bit groups using 360 columns and $N_{QCB_IG}$ rows. In the write operation, bits from the group-wise interleaver output shall be written row-wise as illustrated in the example of Figure 6.8. The read operation shall be performed column-wise to read out 1 bit from each row and an example is shown in Figure 6.9. Note that the Part 1 process is performed on the first bit through the $N_{part1}$-th bit defined in Table 6.11.

For Part 2, the remaining bits excluded from the repeated operation in Part 1 (i.e. $N_{part2}$ bits) shall be mapped to symbols sequentially without performing block interleaving.

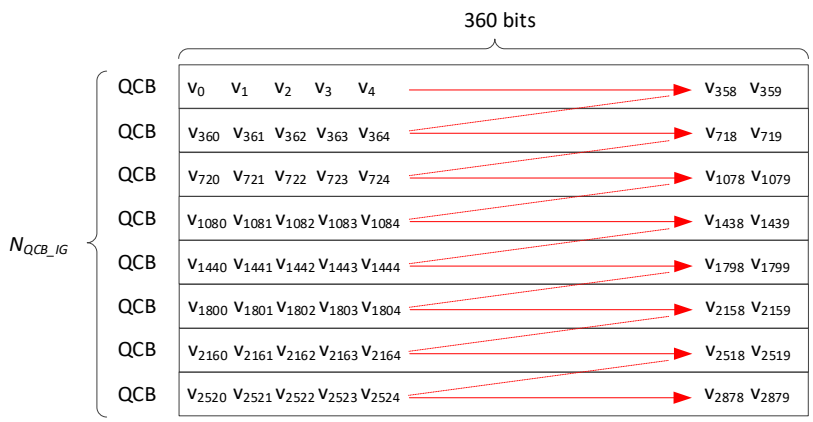


**Figure 6.8** Write operation of Part 1 Type B block interleaving for 256QAM.

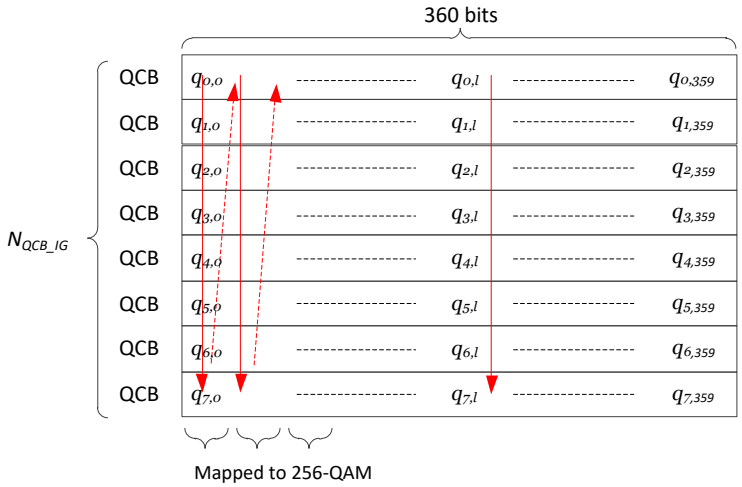


**Figure 6.9** Read operation of Part 1 Type B block interleaving for 256QAM.

## 6.3 Constellation Mapping

This section describes the mapping of FEC encoded and bit-interleaved bits to complex valued quadrature amplitude modulation (QAM) constellation points on the IQ plane. The input to the constellation mapping block is a stream of bit-interleaved FEC Frames and the output is cells, grouped as a FEC Block when necessary.

The Mapper consists of a DeMultiplexer block which followed by a bit-to-IQ mapping block. A block diagram of the Mapper is shown in Figure 6.10. The following sections describe the details to map the input FEC Frame bits to the constellation. First, the bits comprising a FEC Frame shall be demultiplexed into parallel streams as described in Section 6.3.3 to generate data cells. Next the data cells shall be mapped to constellation values, this is described in Section 6.3.4. The details for each type of modulation are described in Section 6.3.4.1 for QPSK, Section 6.3.4.2 for 16QAM to 256QAM and Section 6.3.4.3 for 1024 and 4096 QAM.

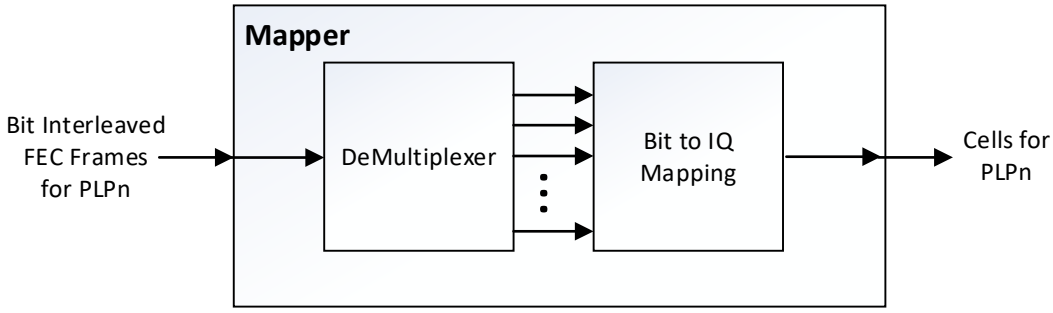


**Figure 6.10** Mapper structure.

### 6.3.1 Constellation Overview

Six different modulation orders are defined: uniform QPSK modulation and five non-uniform constellation (NUC) sizes; 16QAM, 64QAM, 256QAM, 1024QAM and 4096QAM respectively. For each combination of NUC modulation order and code rate a different constellation exists. However, the constellation does not vary with code length, the same constellation is used for both $N_{inner}$=64800 and $N_{inner}$=16200 codes when the code rate and modulation order are held constant. The same QPSK constellation is used for all code rates.

The QPSK constellation is a 1-dimensional QAM form.

The non-uniform constellations 16QAM, 64QAM and 256QAM are 2-dimensional (2D) quadrant-symmetric QAM constellations and are constructed by symmetry from a single quadrant. To reduce the complexity during QAM de-mapping at the receiver, the 1024QAM and 4096QAM constellations are derived from non-uniform 1-dimensional (1D) PAM (pulse amplitude modulation) constellations for both in-phase (I) and quadrature (Q) components.

### 6.3.2 Modulation and Coding Combinations

In order to reduce the implementation complexity, implementation of all the modulation and coding combinations is not mandatory. Table 6.12 and Table 6.13 show the mandatory modulation and coding combinations that must be implemented. Mandatory combinations are shown with a check mark ✔.

**Table 6.12** Mandatory Modulation and Coding Combinations $N_{inner}$ = 64800 Bits

| **Code Rate/ Constellation** | **2/ 15** | **3/ 15** | **4/ 15** | **5/ 15** | **6/ 15** | **7/ 15** | **8/ 15** | **9/ 15** | **10/ 15** | **11/ 15** | **12/ 15** | **13/ 15** |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| QPSK | ✔ | ✔ | ✔ | ✔ | ✔ | ✔ | ✔ | ✔ | | ✔ | | |
| 16QAM | | | ✔ | ✔ | | ✔ | ✔ | ✔ | | ✔ | | |
| 64QAM | | ✔ | ✔ | ✔ | ✔ | ✔ | ✔ | ✔ | ✔ | ✔ | | |
| 256QAM | | | ✔ | ✔ | | ✔ | ✔ | ✔ | ✔ | ✔ | ✔ | ✔ |
| 1024QAM | | | | ✔ | | ✔ | ✔ | ✔ | ✔ | ✔ | ✔ | ✔ |
| 4096QAM | | | | | | ✔ | | ✔ | | ✔ | ✔ | ✔ |

**Table 6.13** Mandatory Modulation and Coding Combinations $N_{inner}$ = 16200 Bits

| **Code Rate/ Constellation** | **2/ 15** | **3/ 15** | **4/ 15** | **5/ 15** | **6/ 15** | **7/ 15** | **8/ 15** | **9/ 15** | **10/ 15** | **11/ 15** | **12/ 15** | **13/ 15** |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| QPSK | ✔ | ✔ | ✔ | ✔ | ✔ | ✔ | ✔ | ✔ | | | | |
| 16QAM | | | | ✔ | ✔ | ✔ | ✔ | | | ✔ | | |
| 64QAM | | | | ✔ | ✔ | ✔ | ✔ | ✔ | ✔ | ✔ | | |
| 256QAM | | | | ✔ | | ✔ | ✔ | ✔ | ✔ | ✔ | ✔ | ✔ |

### 6.3.3 Demultiplexing Operation

The operation to map bits from each FEC Frame to parallel streams before constellation mapping is known as demultiplexing. The number of output data cells for each FEC Frame input and the effective number of bits per cell $\eta_{MOD}$ is defined in Table 6.14.

**Table 6.14** Parameters for Bit-Mapping into Constellations

| **Modulation** | **$\eta_{MOD}$** | **No. output data cells** ***$N_{inner}$ = 64800 bits*** | **No. output data cells** ***$N_{inner}$ = 16200 bits*** |
|---|---|---|---|
| QPSK | 2 | 32400 | 8100 |
| 16QAM | 4 | 16200 | 4050 |
| 64QAM | 6 | 10800 | 2700 |
| 256QAM | 8 | 8100 | 2025 |
| 1024QAM | 10 | 6480 | N/A |
| 4096QAM | 12 | 5400 | N/A |

The bit-stream $q_j$ from the output of the block-interleaver within the bit interleaver shall be de-multiplexed into $\eta_{MOD}$ sub-streams, as shown in Figure 6.11. The output of the de-multiplexer is a vector denoted as $(y_{0,s}, ..., y_{\eta MOD-1,s})$, with the first index describing the bit-level position, and the index $s$ describing the discrete time index for enumerating all output data cells for one FEC Block.

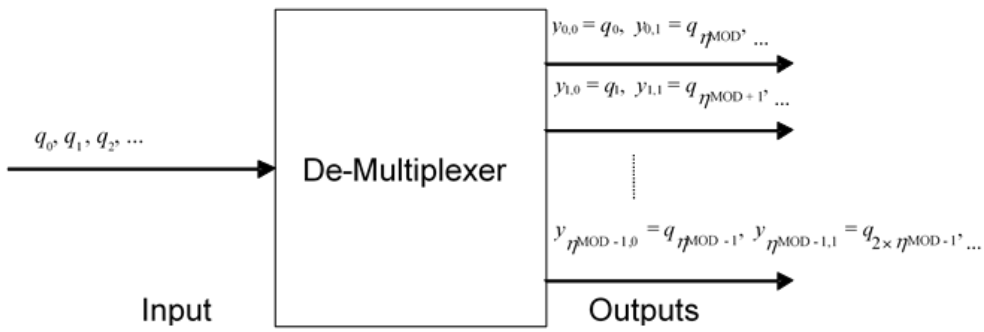


**Figure 6.11** De-multiplexing of bits into sub-streams.

### 6.3.4 Bit to IQ Mapping

#### 6.3.4.1 QPSK

The same constellation mapping for QPSK shall be used for all code rates.

A two-bit input ($y_{0,s}$, $y_{1,s}$) shall be mapped to data cells following the mapping in Table C.1.1, where the first column represents the bits ($y_{0,s}$, $y_{1,s}$) and the second column represents the cell value at the output of the constellation mapper.

#### 6.3.4.2 16QAM, 64QAM and 256QAM

For 16QAM, 64QAM and 256QAM, each input data cell word ($y_{0,s}$, ..., $y_{\eta MOD-1,s}$) shall be modulated using a 2D non-uniform constellation to give a constellation point $z_s$. Index $s$ denotes the discrete time index, and $\eta_{MOD}$ is the number of bits per constellation symbol as defined in Table 6.14.

The vector of complex constellation points $\mathbf{x} = (x_0, \ldots, x_{M-1})$ includes all $M$ constellation points of the QAM alphabet. The $k$-th element of this vector, $\mathbf{x}_k$, corresponds to the QAM constellation point for the input cell word ($y_{0,s}$, …, $y_{\eta MOD-1,s}$), if these bits take on the decimal number $k$ ($y_{0,s}$ being the most significant bit (MSB), and $y_{\eta MOD-1,s}$ being the least significant bit (LSB)). Due to the quadrant symmetry, the complete vector $\mathbf{x}$ shall be derived by defining just the first quarter of the complex constellation points, i.e., ($x_0$, …, $x_{M/4-1}$), which corresponds to the first quadrant. The generation rule for the remaining points shall be as described below. Defining b = M/4, the first quarter of complex constellation points shall be denoted as the NUC position vector $\mathbf{w} = (w_0, \ldots, w_{b-1})$, where the position vectors are defined in Table C.1.2 to Table C.1.7.

As an example, the NUC position vector for 16QAM comprises the complex constellation points with the labels corresponding to the decimal values 0, i.e., ($y_{0,s}$, …, $y_{\eta MOD-1,s}$) = 0000, to b - 1, i.e., ($y_{0,s}$, …, $y_{\eta MOD-1,s}$) = 0011. The remaining constellation points are derived as follows:

| | | |
|---|---|---|
| $(x_0, \ldots, x_{b-1})$ | $= \mathbf{w}$ | (first quarter) |
| $(x_b, \ldots, x_{2b-1})$ | $= -\mathrm{conj}(\mathbf{w})$ | (second quarter) |
| $(x_{2b}, \ldots, x_{3b-1})$ | $= \mathrm{conj}(\mathbf{w})$ | (third quarter) |
| $(x_{3b}, \ldots, x_{4b-1})$ | $= -\mathbf{w}$ | (fourth quarter), |

with conj being the complex conjugate.

#### 6.3.4.2.1 Example

The NUC position vector for 16QAM and code rate 6/15 is constructed as follows. From Table C.1.2 **w** = (0.5115+j1.2092, 1.2092+j0.5115, 0.2663+j0.4530, 0.4530+j0.2663). Here and in the following, j=√(-1) is the imaginary unit. Assuming the input data cell word is ($y_{0,s}$, …, $y_{\eta MOD-1,s}$) = (1100), the corresponding QAM constellation point at time index $s$ is $z_s = x_{12} = -w_0 = -0.5115-j1.2092$. The complete constellation for this NUC position vector is shown in Figure 6.12 with all input data cells marked at the corresponding constellation points.

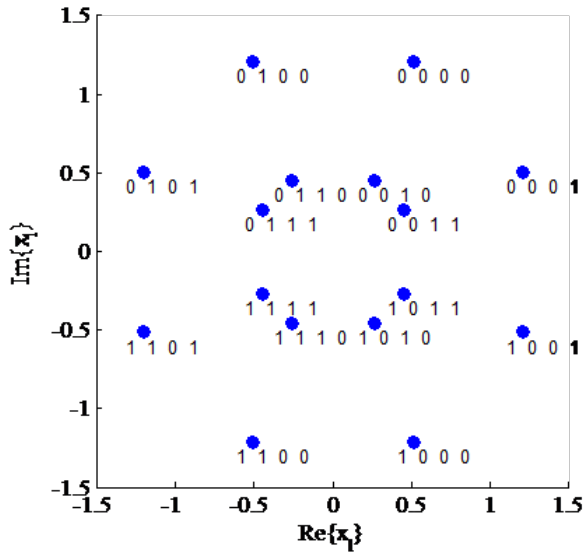


**Figure 6.12** Example 16-NUC for code rate 6/15.

### 6.3.4.3 1024QAM and 4096QAM

For 1024QAM and 4096QAM each input data cell word ($y_{0,s}$, …, $y_{\eta MOD-1,s}$) at discrete time index $s$ shall be modulated using a 1-dimensional non-uniform QAM constellation to give a constellation point $z_s$ prior to normalization. 1-dimensional refers to the fact that a 2-dimensional QAM constellation can be separated into two 1-dimensional PAM constellations, one for each I and Q component. The exact values of the real and imaginary components Re($z_s$) and Im($z_s$) for each combination of the relevant input cell word ($y_{0,s}$, …, $y_{\eta MOD-1,s}$) shall be given by a 1D-NUC position vector **u** = ($u_0$, …, $u_{v-1}$), where the position vectors are defined in Table C.1.8 to Table C.1.11 and the bit labels are defined in Table C.3.1 to Table C.3.4. Vector **u** defines the constellation point positions of the non-uniform constellation in one dimension. The number of elements of the 1D-NUC position vector **u** is defined by

$$v = \frac{\sqrt{M}}{2}$$

#### 6.3.4.3.1 Example

The 1024-NUC for code rate 6/15 is defined by the NUC position vector from Table C.1.8, where **u** = ($u_0$, ..., $u_{15}$) = (0.1275, 0.1276, 0.1294, 0.1295, 0.3424, 0.3431, 0.3675, 0.3666, 0.6097, 0.6072, 0.7113, 0.7196, 0.9418, 1.0048, 1.2286, 1.5031). Assuming the input data cell ($y_{0,s}$, …, $y_{\eta MOD-1,s}$)

= (0010011100) the corresponding QAM constellation point $z_s$ has $\mathrm{Im}(z_s) = u_3 = 0.1295$ (defined by even index bit labels, i.e., 01010) and $\mathrm{Re}(z_s) = u_{11} = 0.7196$ (defined by odd index bit label, i.e., 00110). The complete constellation for this NUC position vector is shown in Figure 6.13.

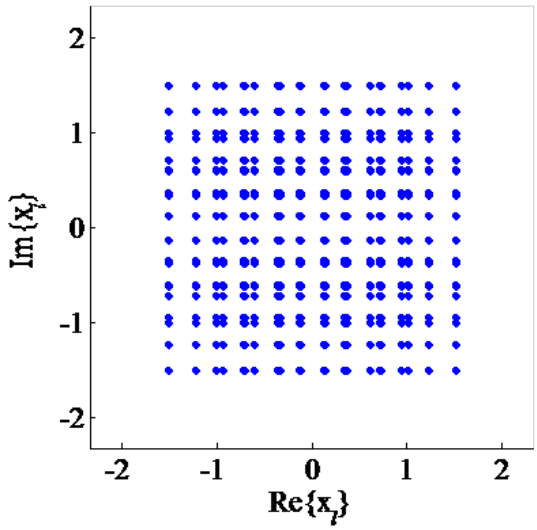


**Figure 6.13** Example 1024-NUC for code rate 6/15.

## 6.4 Layered Division Multiplexing (LDM)

LDM is a constellation superposition technology that combines multiple PLPs at different power levels, often with different modulation and channel coding schemes, before transmission in one RF channel.

In this version of the specification only two-layer LDM is defined. The two layers shall be called Core Layer and Enhanced Layer, respectively.

### 6.4.1 LDM Encoding

The block diagram of the encoding of a two-layer LDM system is shown in Figure 6.14.

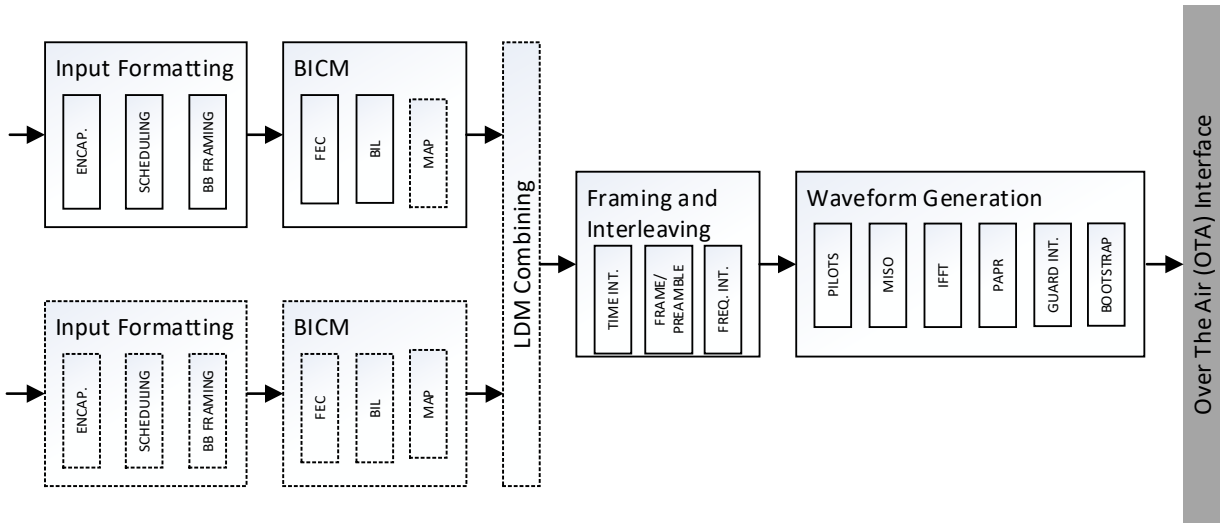


**Figure 6.14** Block diagram of LDM encoding.

A two-layer LDM system shall combine two or more PLPs before time interleaving. Each layer shall consist of one or more PLPs. The Core Layer shall use an equal or more robust ModCod combination than the Enhanced Layer. Each PLP may use a different FEC encoding (including code length and code rate) and constellation mapping. For example the Core Layer might use $N_{inner}$=64800, code rate=4/15 and QPSK while the Enhanced Layer might use $N_{inner}$=64800, code rate=10/15 and 64QAM.

The Core PLPs and Enhanced PLPs shall be combined in an LDM Combiner block, depicted in Figure 6.15 .

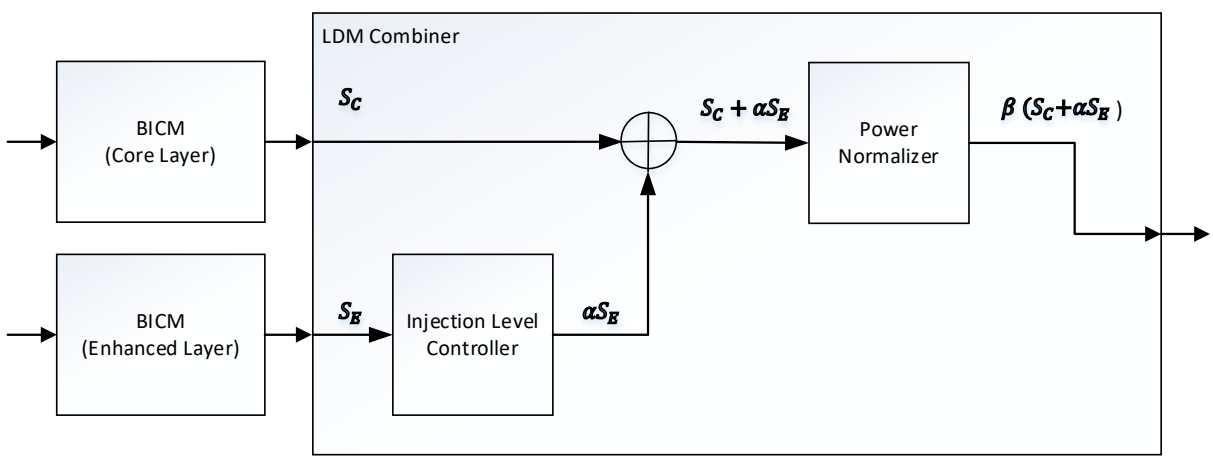


**Figure 6.15** Constellation superposition for two-layer LDM.

An injection level controller shall be used to reduce the power of the Enhanced Layer relative to the Core Layer so as to output the desired transmission energy for each layer. The transmission energy level shall be chosen in combination with the ModCod parameters in order to achieve the desired coverage area as well as the desired bit rate. The Enhanced Layer injection levels relative to the Core Layer are selectable from 0 dB to 25 dB below the Core Layer.

### 6.4.2 Injection Level Controller

The injection level (of the Enhanced Layer signal relative to the Core Layer signal) is a transmission parameter which enables distribution of transmission power between the two layers. By varying the injection level, the transmission robustness of each layer is changed, providing an additional method of varying robustness in addition to the choice of ModCod parameters for each PLP. The dedicated power distributions for each layer according to the various allowed injection levels are listed in Table 6.15.

**Table 6.15** Power Distributions Between Layers for Various Injection Levels

| Injection level of EL below CL level (dB) | CL power ratio relative to total power (%) | EL power ratio relative to total power (%) | Reduction of CL power relative to total power (dB) | Reduction of EL power relative to total power (dB) |
|---|---|---|---|---|
| 0.0 dB | 50.0% | 50.0% | 3.01 | 3.01 |
| +0.5 dB | 52.9% | 47.1% | 2.77 | 3.27 |
| +1.0 dB | 55.7% | 44.3% | 2.54 | 3.54 |
| +1.5 dB | 58.5% | 41.5% | 2.32 | 3.82 |
| +2.0 dB | 61.3% | 38.7% | 2.12 | 4.12 |
| +2.5 dB | 64.0% | 36.0% | 1.94 | 4.44 |
| +3.0 dB | 66.6% | 33.4% | 1.76 | 4.76 |
| +3.5 dB | 69.1% | 30.9% | 1.60 | 5.10 |
| +4.0 dB | 71.5% | 28.5% | 1.46 | 5.46 |
| +4.5 dB | 73.8% | 26.2% | 1.32 | 5.82 |
| +5.0 dB | 76.0% | 24.0% | 1.19 | 6.19 |
| +6.0 dB | 79.9% | 20.1% | 0.97 | 6.97 |
| +7.0 dB | 83.4% | 16.6% | 0.79 | 7.79 |
| +8.0 dB | 86.3% | 13.7% | 0.64 | 8.64 |
| +9.0 dB | 88.8% | 11.2% | 0.51 | 9.51 |
| +10.0 dB | 90.9% | 9.1% | 0.41 | 10.41 |
| +11.0 dB | 92.6% | 7.4% | 0.33 | 11.33 |
| +12.0 dB | 94.1% | 5.9% | 0.27 | 12.27 |
| +13.0 dB | 95.2% | 4.8% | 0.21 | 13.21 |
| +14.0 dB | 96.2% | 3.8% | 0.17 | 14.17 |
| +15.0 dB | 96.9% | 3.1% | 0.14 | 15.14 |
| +16.0 dB | 97.5% | 2.5% | 0.11 | 16.11 |
| +17.0 dB | 98.0% | 2.0% | 0.09 | 17.09 |
| +18.0 dB | 98.4% | 1.6% | 0.07 | 18.07 |
| +19.0 dB | 98.8% | 1.2% | 0.05 | 19.05 |
| +20.0 dB | 99.0% | 1.0% | 0.04 | 20.04 |
| +21.0 dB | 99.2% | 0.8% | 0.03 | 21.03 |
| +22.0 dB | 99.4% | 0.6% | 0.03 | 22.03 |
| +23.0 dB | 99.5% | 0.5% | 0.02 | 23.02 |
| +24.0 dB | 99.6% | 0.4% | 0.02 | 24.02 |
| +25.0 dB | 99.7% | 0.3% | 0.01 | 25.01 |

### 6.4.3 Power Normalizer

After combining the total power of combined signals shall be normalized to unity in the power normalizer block.

The value of the scaling factor of the injection level controller, $\alpha$, and the normalizing factor of the power normalizer, $\beta$, depends on the injection level of the Enhanced Layer. Values allowed are listed in Table 6.16.

**Table 6.16** Scaling and Normalizing Factors According to Enhanced Layer Injection Level

| Injection level of EL below CL level (dB) | Scaling factor $\alpha$ | Normalizing factor $\beta$ | Injection level of EL below CL level (dB) | Scaling factor $\alpha$ | Normalizing factor $\beta$ |
|---|---|---|---|---|---|
| **0.0 dB** | 1.0000000 | 0.7071068 | **+11.0 dB** | 0.2818383 | 0.9625032 |
| **+0.5 dB** | 0.9440609 | 0.7271524 | **+12.0 dB** | 0.2511886 | 0.9698706 |
| **+1.0 dB** | 0.8912509 | 0.7465331 | **+13.0 dB** | 0.2238721 | 0.9758449 |
| **+1.5 dB** | 0.8413951 | 0.7651789 | **+14.0 dB** | 0.1995262 | 0.9806699 |
| **+2.0 dB** | 0.7943282 | 0.7830305 | **+15.0 dB** | 0.1778279 | 0.9845540 |
| **+2.5 dB** | 0.7498942 | 0.8000406 | **+16.0 dB** | 0.1584893 | 0.9876723 |
| **+3.0 dB** | 0.7079458 | 0.8161736 | **+17.0 dB** | 0.1412538 | 0.9901705 |
| **+3.5 dB** | 0.6683439 | 0.8314061 | **+18.0 dB** | 0.1258925 | 0.9921685 |
| **+4.0 dB** | 0.6309573 | 0.8457262 | **+19.0 dB** | 0.1122018 | 0.9937642 |
| **+4.5 dB** | 0.5956621 | 0.8591327 | **+20.0 dB** | 0.1000000 | 0.9950372 |
| **+5.0 dB** | 0.5623413 | 0.8716346 | **+21.0 dB** | 0.0891251 | 0.9960519 |
| **+6.0 dB** | 0.5011872 | 0.8940022 | **+22.0 dB** | 0.0794328 | 0.9968601 |
| **+7.0 dB** | 0.4466836 | 0.9130512 | **+23.0 dB** | 0.0707946 | 0.9975034 |
| **+8.0 dB** | 0.3981072 | 0.9290819 | **+24.0 dB** | 0.0630957 | 0.9980154 |
| **+9.0 dB** | 0.3548134 | 0.9424353 | **+25.0 dB** | 0.0562341 | 0.9984226 |
| **+10.0 dB** | 0.3162278 | 0.9534626 | | | |

### 6.4.4 LDM Example

An example for LDM illustrating a constellation for each of the Core and Enhanced Layers and the resulting constellation after combination and normalization is shown in Figure 6.16 and Figure 6.17.

In this example, the Core Layer uses the code rate 4/15 and QPSK modulation as shown in Figure 6.16(a), and the Enhanced Layer uses the code rate 10/15 and 64-QAM modulation as shown in Figure 6.16(b). The injection level of the Enhanced Layer below the Core Layer is set to 4 dB, where the scaling factors for power normalization are $\alpha = 0.6309573$ and $\beta = 0.8457262$, respectively. The power ratio of the Core Layer relative to the total power is 71.5% whereas the power ratio of the Enhanced Layer relative to the total power is 28.5%. The resulting combined constellation is shown in Figure 6.17.

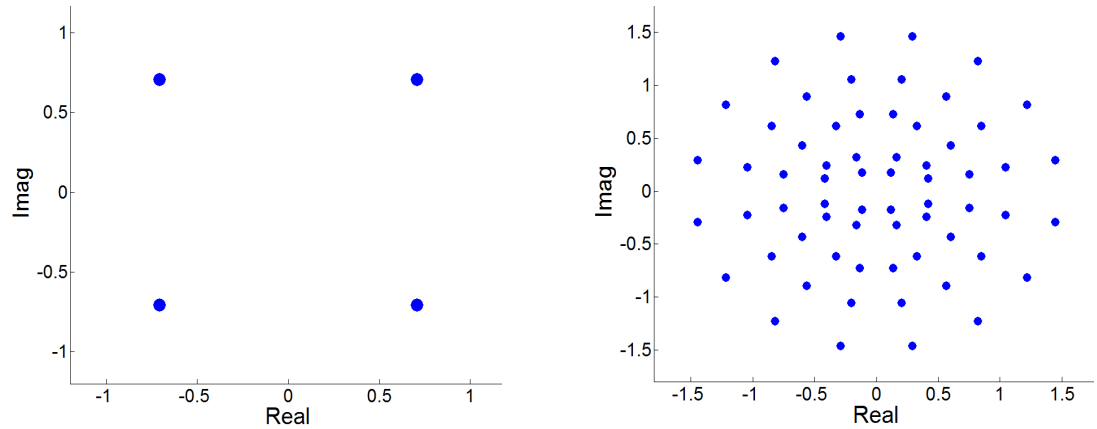


**Figure 6.16** Examples of (*a*, left) Core Layer and (*b*, right) Enhanced Layer constellations.

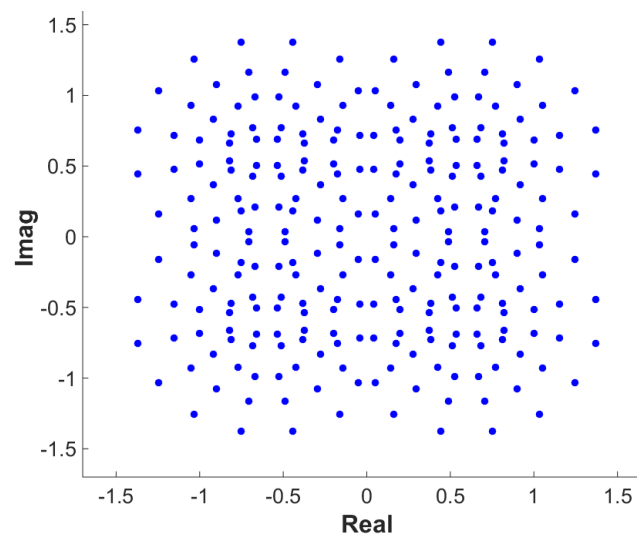


**Figure 6.17** Example combined constellation after normalization.

## 6.5 Protection for L1 Signaling

### 6.5.1 Overview

There are two separate L1 data sections that are input to the framing block to be inserted into the Preamble, L1-Basic data and L1-Detail data. This data shall be protected using the separate encoding methods detailed below. The input to the L1-Basic protection block is the 200 bits of L1-Basic information described in Section 9.2 while the input to the L1-Detail protection block is the variable number of data bits described in Section 9.3. The outputs of the L1-Basic and L1-Detail protection blocks are used in the construction of the Preamble (see Section 7.2.5).

Many of the blocks in L1-Basic and L1-Detail protection are common, these blocks are described in Section 6.5.2. Specific blocks used only for L1-Detail protection are described in Section 6.5.3.

The complete encoding chain of the L1-Basic signaling is shown in Figure 6.18.

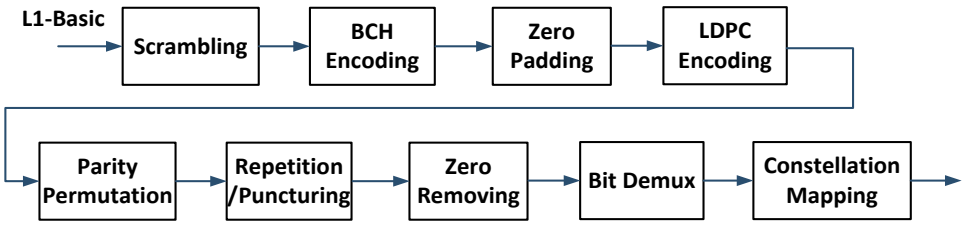


**Figure 6.18** Block diagram of L1-Basic protection.

With reference to Figure 6.18, Scrambling details are described in Section 6.5.2.2, BCH encoding is described in Section 6.5.2.3, Zero padding (or shortening) is described in Section 6.5.2.4, LDPC encoding is described in Section 6.5.2.5, Parity permutation in Section 6.5.2.6, Repetition in Section 6.5.2.7 and Parity Puncturing in Section 6.5.2.8, Zero removal is described in Section 6.5.2.9, Bit Demuxing in Section 6.5.2.10 and Constellation Mapping is described in Section 6.5.2.11.

The complete encoding chain of the L1-Detail signaling is shown in Figure 6.19.

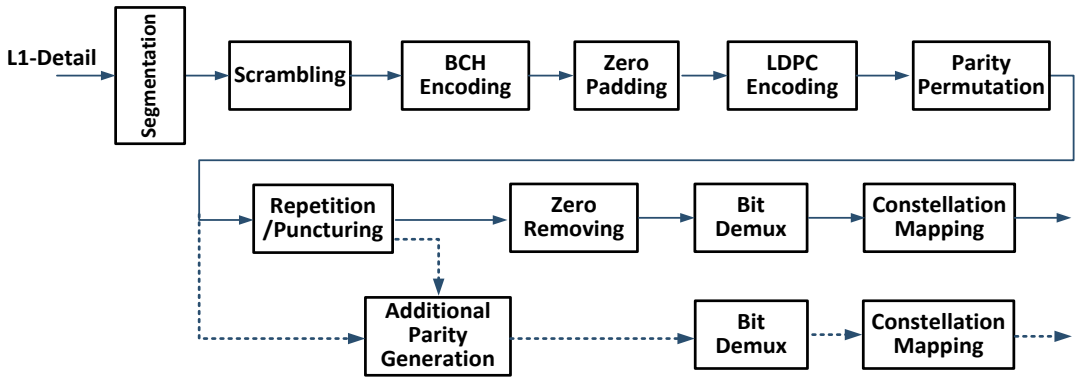


**Figure 6.19** Block diagram of the L1-Detail protection.

The details of the L1-Detail specific blocks shown in Figure 6.19 are as follows. Segmentation details are defined in Section 6.5.3.1 and Additional Parity details are defined in Section 6.5.3.2.

### 6.5.2 Common Blocks for L1-Basic and L1-Detail

#### 6.5.2.1 Overview of Common Blocks

The L1-Basic and L1-Detail signaling are protected by a concatenation of BCH Outer Code and LDPC Inner Code. They shall be first scrambled and then BCH-encoded, where the BCH parity-check bits of the L1-Basic and L1-Detail signaling shall be appended to the L1-Basic and L1-Detail signaling bits, respectively. The concatenated signaling and BCH parity-check bits are further protected by a shortened and punctured 16K LDPC code, as described in sections 6.5.2.8 and 6.5.2.9. When required, repetition is applied before puncturing, as described in Section 6.5.2.7.

To provide various robustness levels suitable for wide SNR range, the protection level of L1-Basic and L1-Detail signaling is categorized into 7 modes based on LDPC codes, modulation order and shortening/puncturing parameter, i.e., a ratio of the number of bits to be punctured to the number of bits to be shortened. Each categorized mode employs a distinct combination of LDPC code, modulation order and constellation and shortening/puncturing pattern.

Table 6.17 presents the ModCod configurations for the 7 modes each of L1-Basic and L1-Detail. The 16K LDPC codes and non-uniform constellations used for L1 signaling protection shall be the same as those for Baseband Packet payload.

$K_{sig}$ means the number of information bits for a coded block, i.e., L1 signaling bits of size $K_{sig}$ correspond to one LDPC coded block. The value of $K_{sig}$ for L1-Basic is fixed as 200, however, the value of $K_{sig}$ for L1-Detail is variable since the amount of L1-Detail signaling bits is variable. Segmentation operation shall be applied to L1-Detail signaling when the number of L1-Detail signaling bits is larger than the maximum value of $K_{sig}$ defined in Table 6.17. Each segmented L1-Detail block of size $K_{sig}$ corresponds to one LDPC coded block. The details of Segmentation are defined in Section 6.5.3.1.

**Table 6.17** Configurations for L1-Basic and L1-Detail Signaling

| Signaling FEC Type | | $K_{sig}$ | Code Length | Code Rate | Constellation | Length (Cells) |
|---|---|---|---|---|---|---|
| **L1-Basic** | Mode 1 | 200 | 16200 | 3/15 (Type A) | QPSK | 3820 |
| | Mode 2 | | | | QPSK | 934 |
| | Mode 3 | | | | QPSK | 484 |
| | Mode 4 | | | | NUC_16_8/15 | 259 |
| | Mode 5 | | | | NUC_64_9/15 | 163 |
| | Mode 6 | | | | NUC_256_9/15 | 112 |
| | Mode 7 | | | | NUC_256_13/15 | 69 |
| **L1-Detail** | Mode 1 | 200 ~ 2352 | | | QPSK | |
| | Mode 2 | 200 ~ 3072 | | | QPSK | |
| | Mode 3 | 200 ~ 6312 | | 6/15 (Type B) | QPSK | |
| | Mode 4 | | | | NUC_16_8/15 | |
| | Mode 5 | | | | NUC_64_9/15 | |
| | Mode 6 | | | | NUC_256_9/15 | |
| | Mode 7 | | | | NUC_256_13/15 | |

#### 6.5.2.2 Scrambling

Every $K_{sig}$ bits of information shall be scrambled before BCH encoding. The generator polynomial, initialization and operation of the scrambler shall be the same as that of the Baseband Packet scrambler described in Section 5.2.3.

#### 6.5.2.3 BCH Encoding

The systematic BCH code for $N_{inner}$ = 16200 defined in Section 6.1.2.1 shall be used for outer encoding of L1-Basic and L1-Detail signaling, followed by zero padding. The parameters for a shortened BCH code are given in Table 6.18.

**Table 6.18** Parameters for BCH Encoding of L1 Information

| **Signaling FEC Type** | | $K_{sig}$ = $K_{payload}$ | $M_{outer}$ | $N_{outer}$ = $K_{sig}$ + $M_{outer}$ |
|---|---|---|---|---|
| **L1-Basic** | Mode 1 | 200 | 168 | 368 |
| | Mode 2 | | | |
| | Mode 3 | | | |
| | Mode 4 | | | |
| | Mode 5 | | | |
| | Mode 6 | | | |
| | Mode 7 | | | |
| **L1-Detail** | Mode 1 | 200 ~ 2352 | | 368 ~ 2520 |
| | Mode 2 | 200 ~ 3072 | | 368 ~ 3240 |
| | Mode 3 | 200 ~ 6312 | | 368 ~ 6480 |
| | Mode 4 | | | |
| | Mode 5 | | | |
| | Mode 6 | | | |
| | Mode 7 | | | |

6.5.2.4 Zero Padding

Some of the information bits of the 16K LDPC code shall be padded with zeros in order to fill $K_{ldpc}$ information bits. The padding bits shall not be transmitted. Here, $K_{ldpc}$ is the number of LDPC encoder input information bits and has the same value of $K_{payload}$ in the case of no Outer Code for $N_{inner}$ =16200 in Section 6.1.1.

All $K_{ldpc}$ LDPC information bits, denoted by $\{i_0, i_1, \ldots, i_{Kldpc-1}\}$, shall be divided into $N_{info_group}$ (= $K_{ldpc}$/360) groups as follows:

$$Z_j = \left\{ i_k \middle| j = \left\lfloor \frac{k}{360} \right\rfloor, 0 \le k < K_{ldpc} \right\} \text{ for } 0 \le j < N_{info_group}$$

where $Z_j$ represents the $j$th bit group. The parameters ($N_{outer}$, $K_{ldpc}$, $N_{info_group}$) for L1-Basic and L1-Detail signaling data are given in Table 6.19.

**Table 6.19** Parameters for Zero Padding

| **Signaling FEC Type** | $N_{outer}$ | $K_{ldpc}$ | $N_{info_group}$ |
|---|---|---|---|
| **L1-Basic** (all modes) | 368 | 3240 | 9 |
| **L1-Detail Mode 1** | 368 ~ 2520 | | |
| **L1-Detail Mode 2** | 368 ~ 3240 | | |
| **L1-Detail Mode 3** | 368 ~ 6480 | 6480 | 18 |
| **L1-Detail Mode 4** | | | |
| **L1-Detail Mode 5** | | | |
| **L1-Detail Mode 6** | | | |
| **L1-Detail Mode 7** | | | |

For $0 \le j < N_{info_group}$, each bit group $Z_j$ has 360 bits, as shown in Figure 6.20.

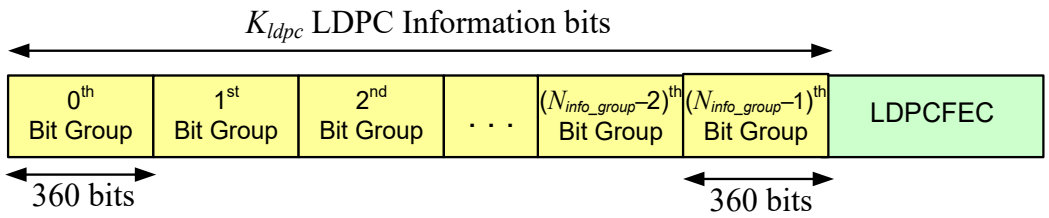


**Figure 6.20** Format of data after LDPC encoding of L1-Basic/-Detail signaling.

When the length of BCH encoded bits for L1-Basic and L1-Detail signaling, i.e. $N_{outer}(= K_{sig}+ M_{outer}) < K_{ldpc}$, the $K_{ldpc}$ LDPC information bits shall be filled with $N_{outer}$ BCH encoded bits and $(K_{ldpc} - N_{outer})$ zero-padded bits for LDPC encoding.

For the given $N_{outer}$, the number of zero-padding bits shall be calculated as $(K_{ldpc} - N_{outer})$. Then, the shortening procedure shall be as follows:

**Step 1**) Compute the number of groups in which all the bits shall be padded, $N_{pad}$ such that

$$N_{pad} = \left\lfloor \frac{K_{ldpc} - N_{outer}}{360} \right\rfloor.$$

**Step 2**) When $N_{pad}$ is not zero, determine the list of $N_{pad}$ groups, $Z_{\pi_S(0)}, Z_{\pi_S(1)}, \ldots, Z_{\pi_S(N_{pad}-1)}$, with $\pi_S(j)$ being the shortening pattern order of the $j$-th bit group to be as described in Table 6.20. The information bits of the determined groups shall be padded with zeros. When $N_{\mathrm{pad}}$ is zero, then the above procedure shall be skipped.

**Step 3**) For the group $Z_{\pi_S(N_{pad})}$, $(K_{ldpc} - N_{outer} - 360 \times N_{pad})$ information bits in the first part of $Z_{\pi_S(N_{pad})}$ shall be additionally padded with zeros.

**Step 4**) Finally, $N_{outer}$ BCH encoded bits shall be sequentially mapped to bit positions which are not padded in $K_{ldpc}$ LDPC information bits, $\{i_0, i_1, \ldots, i_{Kldpc-1}\}$ by the above procedure.

**Table 6.20** Shortening Pattern of Information Bit Group to be Padded

| Signaling FEC Type | $N_{group}$ | $\pi_S(j)$ $(0 \le j < N_{group})$ | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | $\pi_S(0)$ | $\pi_S(1)$ | $\pi_S(2)$ | $\pi_S(3)$ | $\pi_S(4)$ | $\pi_S(5)$ | $\pi_S(6)$ | $\pi_S(7)$ | $\pi_S(8)$ |
| | | $\pi_S(9)$ | $\pi_S(10)$ | $\pi_S(11)$ | $\pi_S(12)$ | $\pi_S(13)$ | $\pi_S(14)$ | $\pi_S(15)$ | $\pi_S(16)$ | $\pi_S(17)$ |
| **L1-Basic** (for all modes) | 9 | 4 | 1 | 5 | 2 | 8 | 6 | 0 | 7 | 3 |
| | | - | - | - | - | - | - | - | - | - |
| **L1-Detail Mode 1** | | 7 | 8 | 5 | 4 | 1 | 2 | 6 | 3 | 0 |
| | | - | - | - | - | - | - | - | - | - |
| **L1-Detail Mode 2** | | 6 | 1 | 7 | 8 | 0 | 2 | 4 | 3 | 5 |
| | | - | - | - | - | - | - | - | - | - |
| **L1-Detail Mode 3** | 18 | 0 | 12 | 15 | 13 | 2 | 5 | 7 | 9 | 8 |
| | | 6 | 16 | 10 | 14 | 1 | 17 | 11 | 4 | 3 |
| **L1-Detail Mode 4** | | 0 | 15 | 5 | 16 | 17 | 1 | 6 | 13 | 11 |
| | | 4 | 7 | 12 | 8 | 14 | 2 | 3 | 9 | 10 |
| **L1-Detail Mode 5** | | 2 | 4 | 5 | 17 | 9 | 7 | 1 | 6 | 15 |
| | | 8 | 10 | 14 | 16 | 0 | 11 | 13 | 12 | 3 |
| **L1-Detail Mode 6** | | 0 | 15 | 5 | 16 | 17 | 1 | 6 | 13 | 11 |
| | | 4 | 7 | 12 | 8 | 14 | 2 | 3 | 9 | 10 |
| **L1-Detail Mode 7** | | 15 | 7 | 8 | 11 | 5 | 10 | 16 | 4 | 12 |
| | | 3 | 0 | 6 | 9 | 1 | 14 | 17 | 2 | 13 |

#### 6.5.2.5 LDPC Encoding

The $K_{ldpc}$ output bits ($i_0, i_1, \ldots, i_{Kldpc-1}$) from zero inserter, including the ($K_{ldpc} - N_{outer}$) zero padding bits and the $M_{outer} = (N_{outer} - K_{sig})$ BCH parity-check bits constitute the $K_{ldpc}$ information bits $\boldsymbol{I} = (i_0, i_1, \ldots, i_{Kldpc-1})$ for the LDPC encoder. The LDPC encoder shall systematically encode the $K_{ldpc}$ information bits onto a codeword $\boldsymbol{\Lambda}$ of size $N_{inner}$: $\boldsymbol{\Lambda} = (c_0, c_1, \ldots, c_{Ninner-1}) = (i_0, i_1, \ldots, i_{Kldpc-1}, p_0, p_1, \ldots, p_{Ninner-Kldpc-1})$ according to Section 6.1.3.1 (for all L1-Basic Modes and L1-Detail Modes 1 and 2) or Section 6.1.3.2 (for L1-Detail Modes 3, 4, 5, 6 and 7). The LDPC configurations are given in Table 6.6 and Table 6.7.

#### 6.5.2.6 Parity Permutation

The parity permutation shall be performed only for the parity part (not information part), and the operation shall consist of a parity interleaver and group-wise parity permutation.

Parity interleaving shall be used for L1-Detail Modes 3, 4, 5, 6 and 7 and shall not be used for L1-Basic and L1-Detail Modes 1 and 2, since parity interleaving is already included as part of the LDPC encoding process in these latter modes.

The parity interleaver output is denoted by $\boldsymbol{U} = (u_0, u_1, \ldots, u_{Nldpc-1})$. In the parity interleaving, parity bits shall be interleaved as:

$$u_i = c_i \quad \text{for } 0 \le i < K_{ldpc} \text{ (information bits are not interleaved.)}$$

$$u_{K_{ldpc}+360t+s} = c_{K_{ldpc}+27s+t} \quad \text{for } 0 \le s < 360,\ 0 \le t < 27.$$

For L1-Basic and L1-Detail Modes 1 and 2, the parity interleaver is not used. Therefore

$$u_i = c_i \ \text{ for } 0 \le i < N_{inner}.$$

The parity interleaved LDPC coded bits, ($u_0$, $u_1$, ..., $u_{Nldpc-1}$), shall be split into $N_{group}$ = $N_{ldpc}$/360 bit groups as follows:

$$X_j = \{u_k | 360 \times j \leq k < 360 \times (j+1), 0 \leq k < N_{inner}\} \text{ for } 0 \leq j < N_{group},$$

where $X_j$ represents the $j$-th bit group. Each bit group $X_j$ has 360 bits, as illustrated in Figure 6.21.

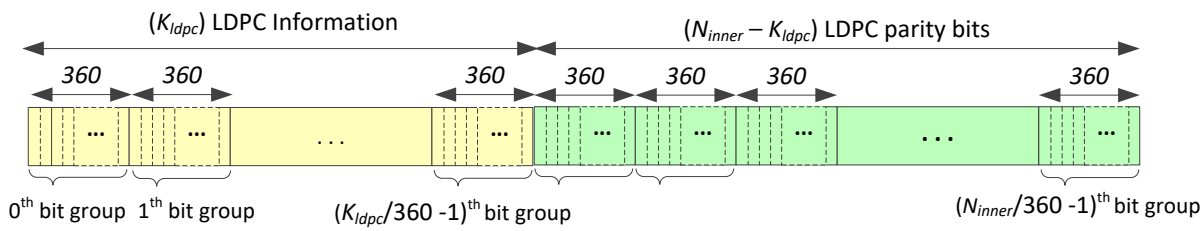


**Figure 6.21** Parity interleaved LDPC codeword bit groups.

The information bits among the parity-interleaved LDPC bits shall not be interleaved by the group-wise interleaver while the parity bits among the parity-interleaved LDPC bits shall be interleaved by the group-wise interleaver as follows:

$$Y_j = X_j, \ 0 \leq j < K_{ldpc}/360$$

$$Y_j = X_{\pi_P(j)}, \ K_{ldpc}/360 \leq j < N_{group}$$

where $Y_j$ represents the group-wise interleaved $j$-th bit group and $\pi_P(j)$ denotes the permutation order for group-wise interleaving. LDPC parity bits are arranged such that parity bit groups are arranged in a reverse order of puncturing pattern by parity permutation. Table 6.21 and Table 6.22 show the permutation order of the group-wise interleaving $\pi_P(j)$ for the parity part.

**Table 6.21** Group-wise Interleaving Pattern for all L1-Basic Modes, L1-Detail Modes 1 and 2

| Signaling FEC Type | $N_{group}$ | Order of Group-Wise Interleaving $\pi_P(j)$ $(9 \leq j < 45)$ | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | $\pi_p(9)$ | $\pi_p(10)$ | $\pi_p(11)$ | $\pi_p(12)$ | $\pi_p(13)$ | $\pi_p(14)$ | $\pi_p(15)$ | $\pi_p(16)$ | $\pi_p(17)$ | $\pi_p(18)$ | $\pi_p(19)$ | $\pi_p(20)$ |
| | | $\pi_p(21)$ | $\pi_p(22)$ | $\pi_p(23)$ | $\pi_p(24)$ | $\pi_p(25)$ | $\pi_p(26)$ | $\pi_p(27)$ | $\pi_p(28)$ | $\pi_p(29)$ | $\pi_p(30)$ | $\pi_p(31)$ | $\pi_p(32)$ |
| | | $\pi_p(33)$ | $\pi_p(34)$ | $\pi_p(35)$ | $\pi_p(36)$ | $\pi_p(37)$ | $\pi_p(38)$ | $\pi_p(39)$ | $\pi_p(40)$ | $\pi_p(41)$ | $\pi_p(42)$ | $\pi_p(43)$ | $\pi_p(44)$ |
| **L1-Basic** (all modes) | 45 | 20 | 23 | 25 | 32 | 38 | 41 | 18 | 9 | 10 | 11 | 31 | 24 |
| | | 14 | 15 | 26 | 40 | 33 | 19 | 28 | 34 | 16 | 39 | 27 | 30 |
| | | 21 | 44 | 43 | 35 | 42 | 36 | 12 | 13 | 29 | 22 | 37 | 17 |
| **L1-Detail Mode 1** | | 16 | 22 | 27 | 30 | 37 | 44 | 20 | 23 | 25 | 32 | 38 | 41 |
| | | 9 | 10 | 17 | 18 | 21 | 33 | 35 | 14 | 28 | 12 | 15 | 19 |
| | | 11 | 24 | 29 | 34 | 36 | 13 | 40 | 43 | 31 | 26 | 39 | 42 |
| **L1-Detail Mode 2** | | 9 | 31 | 23 | 10 | 11 | 25 | 43 | 29 | 36 | 16 | 27 | 34 |
| | | 26 | 18 | 37 | 15 | 13 | 17 | 35 | 21 | 20 | 24 | 44 | 12 |
| | | 22 | 40 | 19 | 32 | 38 | 41 | 30 | 33 | 14 | 28 | 39 | 42 |

**Table 6.22** Group-wise Interleaving Pattern for L1-Detail Modes 3, 4, 5, 6 and 7

| Signaling FEC Type | $N_{group}$ | Order of Group-Wise Interleaving $\pi_P(j)$ $(18 \leq j < 45)$ | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | $\pi_p(18)$ | $\pi_p(19)$ | $\pi_p(20)$ | $\pi_p(21)$ | $\pi_p(22)$ | $\pi_p(23)$ | $\pi_p(24)$ | $\pi_p(25)$ | $\pi_p(26)$ | $\pi_p(27)$ | $\pi_p(28)$ | $\pi_p(29)$ | $\pi_p(30)$ | $\pi_p(31)$ |
| | | $\pi_p(32)$ | $\pi_p(33)$ | $\pi_p(34)$ | $\pi_p(35)$ | $\pi_p(36)$ | $\pi_p(37)$ | $\pi_p(38)$ | $\pi_p(39)$ | $\pi_p(40)$ | $\pi_p(41)$ | $\pi_p(42)$ | $\pi_p(43)$ | $\pi_p(44)$ | |
| **L1-Detail Mode 3** | 45 | 19 | 37 | 30 | 42 | 23 | 44 | 27 | 40 | 21 | 34 | 25 | 32 | 29 | 24 |
| | | 26 | 35 | 39 | 20 | 18 | 43 | 31 | 36 | 38 | 22 | 33 | 28 | 41 | |
| **L1-Detail Mode 4** | | 20 | 35 | 42 | 39 | 26 | 23 | 30 | 18 | 28 | 37 | 32 | 27 | 44 | 43 |
| | | 41 | 40 | 38 | 36 | 34 | 33 | 31 | 29 | 25 | 24 | 22 | 21 | 19 | |
| **L1-Detail Mode 5** | | 19 | 37 | 33 | 26 | 40 | 43 | 22 | 29 | 24 | 35 | 44 | 31 | 27 | 20 |
| | | 21 | 39 | 25 | 42 | 34 | 18 | 32 | 38 | 23 | 30 | 28 | 36 | 41 | |
| **L1-Detail Mode 6** | | 20 | 35 | 42 | 39 | 26 | 23 | 30 | 18 | 28 | 37 | 32 | 27 | 44 | 43 |
| | | 41 | 40 | 38 | 36 | 34 | 33 | 31 | 29 | 25 | 24 | 22 | 21 | 19 | |
| **L1-Detail Mode 7** | | 44 | 23 | 29 | 33 | 24 | 28 | 21 | 27 | 42 | 18 | 22 | 31 | 32 | 37 |
| | | 43 | 30 | 25 | 35 | 20 | 34 | 39 | 36 | 19 | 41 | 40 | 26 | 38 | |

#### 6.5.2.7 Repetition

For L1-Basic Mode 1 and L1-Detail Mode 1 only, additional $N_{repeat}$ bits shall be selected from within the encoded LDPC codeword and transmitted. Repetition shall not be performed for any other modes.

The repetition procedure is as follows:

**Step 1)** For a given $N_{outer}$, the number of parity bits to be additionally transmitted per LDPC codeword, $N_{repeat}$, shall be calculated by multiplying $N_{outer}$ by a fixed number $C$ and adding an even integer $D$. The values of $C$ and $D$ shall be selected according to Table 6.23.

$$N_{repeat} = 2 \times \lfloor C \times N_{outer} \rfloor + D.$$

**Table 6.23** Parameters for Repetition

| | $N_{outer}$ | $K_{sig}$ | $K_{ldpc}$ | $C$ | $D$ | $N_{ldpc_parity}$ (= $N_{inner} - K_{ldpc}$) | $\eta_{MOD}$ |
|---|---|---|---|---|---|---|---|
| **L1-Basic Mode 1** | 368 | 200 | 3240 | 0 | +3672 | 12960 | 2 |
| **L1-Detail Mode 1** | 368 ~ 2520 | 200 ~ 2352 | 3240 | 61/16 | – 508 | 12960 | 2 |

**Step 2)** If $N_{repeat} \leq N_{ldpc_parity}$, the first $N_{repeat}$ bits of the LDPC parity with parity permutation shall be appended to the LDPC information bits, as shown in Figure 6.22.

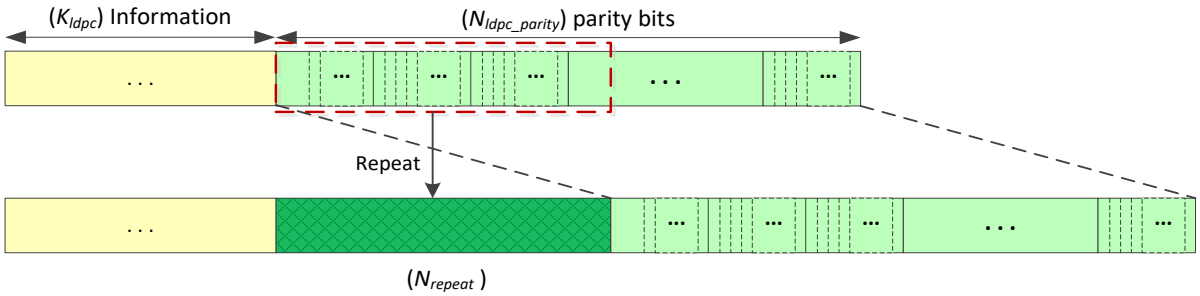


**Figure 6.22** Parity Repetition ($\boldsymbol{N_{repeat} \leq N_{ldpc_parity}}$).

If $N_{repeat} > N_{ldpc_parity}$, the $N_{ldpc_parity}$ bits of the LDPC parity with parity permutation shall be appended to the LDPC information bits and the first $(N_{repeat} - N_{ldpc_parity})$ bits of the LDPC parity with parity permutation shall be additionally appended to the first appended $N_{ldpc_parity}$ bits, as shown in Figure 6.23.

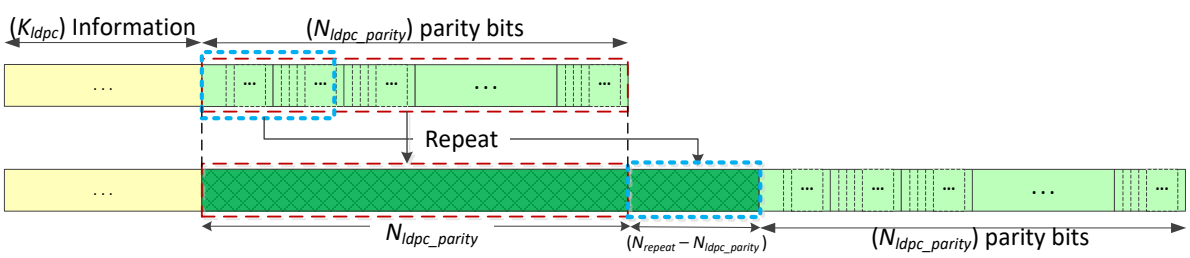


**Figure 6.23** Parity Repetition ($\boldsymbol{N_{repeat} > N_{ldpc_parity}}$).

#### 6.5.2.8 Parity Puncturing

Some LDPC parity bits are punctured after parity permutation. These punctured bits are not transmitted in the frame carrying the L1 signaling bits.

For a given $N_{outer}$, the number of parity bits to be punctured per LDPC codeword and the size of one coded block shall be determined as described in the following steps:

**Step 1)**

$$N_{punc_temp} = \lfloor A \times (K_{ldpc} - N_{outer}) \rfloor + B$$

Depending on the Mode, the temporary size of puncturing bits shall be calculated by multiplying the shortening length by a ratio of the number of bits to be punctured to the number

of bits to be shortened, $A$, and adding a constant integer $B$. $K_{ldpc}$, $A$ and $B$ shall be selected according to Table 6.24.

**Table 6.24** Parameters for Puncturing

| Signaling FEC Type | | $N_{outer}$ | $K_{ldpc}$ | $A$ | $B$ | $N_{ldpc_parity}$ | $\eta_{MOD}$ |
|---|---|---|---|---|---|---|---|
| L1-Basic | Mode 1 | 368 | 3240 | 0 | 9360 | 12960 | 2 |
| | Mode 2 | | | | 11460 | | 2 |
| | Mode 3 | | | | 12360 | | 2 |
| | Mode 4 | | | | 12292 | | 4 |
| | Mode 5 | | | | 12350 | | 6 |
| | Mode 6 | | | | 12432 | | 8 |
| | Mode 7 | | | | 12776 | | 8 |
| L1-Detail | Mode 1 | 368 ~ 2520 | | 7/2 | 0 | | 2 |
| | Mode 2 | 368 ~ 3240 | | 2 | 6036 | | 2 |
| | Mode 3 | 368 ~ 6480 | 6480 | 11/16 | 4653 | 9720 | 2 |
| | Mode 4 | | | 29/32 | 3200 | | 4 |
| | Mode 5 | | | 3/4 | 4284 | | 6 |
| | Mode 6 | | | 11/16 | 4900 | | 8 |
| | Mode 7 | | | 49/256 | 8246 | | 8 |

**Step 2**)

$$N_{FEC_temp} = N_{outer} + N_{ldpc_parity} - N_{punc_temp}$$

where the number of LDPC parity bits, $N_{ldpc_parity}$ shall be selected according to Table 6.24.

**Step 3**)

$$N_{FEC} = \left\lceil \frac{N_{FEC_temp}}{\eta_{MOD}} \right\rceil \times \eta_{MOD},$$

where $\eta_{MOD}$ denotes the modulation order, which is defined in Table 6.24. $N_{FEC}$ is an integer multiple of the modulation order.

**Step 4**)

$$N_{punc} = N_{punc_temp} - (N_{FEC} - N_{FEC_temp})$$

where $N_{FEC}$ denotes the total number of encoded bits by BCH and LDPC for each information block.

The last $N_{punc}$ bits of the whole LDPC codeword with parity permutation and repetition shall be punctured as shown in Figure 6.24 and Figure 6.25 when $N_{punc}$ is a positive integer. Note that the repetition is applied only for L1-Basic Mode 1 and L1-Detail Mode 1.

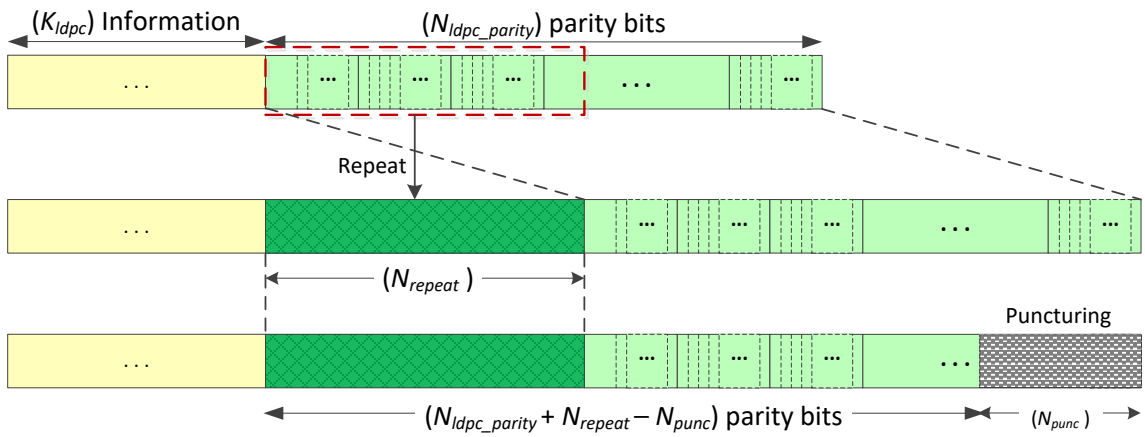


**Figure 6.24** Example 1 of parity puncturing after repetition.

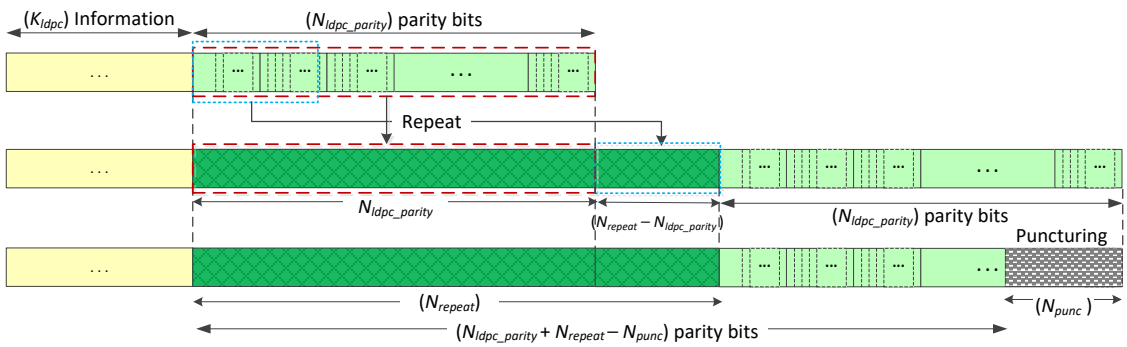


**Figure 6.25** Example 2 of parity puncturing after repetition.

### 6.5.2.9 Zero Removal

The ($K_{ldpc}$ – $N_{outer}$) zero padding bits shall be removed and shall not be transmitted. This leaves a word consisting of the $K_{sig}$ information bits, followed by the 168 BCH parity bits and ($N_{inner}$ – $K_{ldpc}$ – $N_{punc}$) or ($N_{inner}$ – $K_{ldpc}$ – $N_{punc}$ + $N_{repeat}$) parity bits, as illustrated in Figure 6.26. Note that the length of the whole LDPC codeword with repetition is ($N_{FEC}$ + $N_{repeat}$).

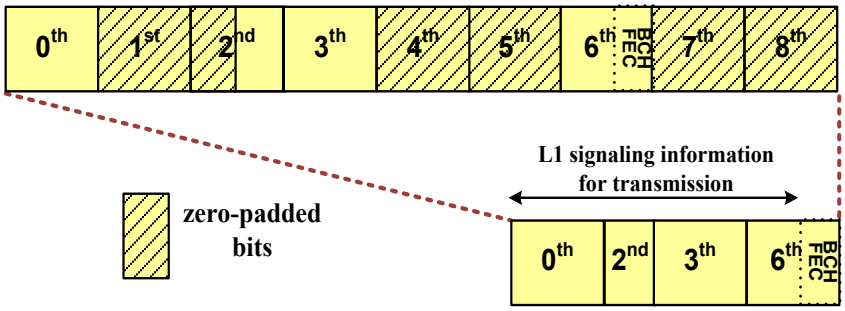


**Figure 6.26** Example of removal of zero-padding bits.

#### 6.5.2.10 Bit Demuxing

Following zero padded bit removal, the remaining bits of length $N_{FEC}$ or ($N_{FEC} + N_{repeat}$) shall be written serially into the Block Interleaver column-wise, where the number of columns shall be the same as the modulation order.

In the read operation, the bits for one constellation symbol shall be read out sequentially row-wise and fed into the bit demultiplexer block. These operations shall continue until the end of the column. Figure 6.27 shows the block interleaving process.

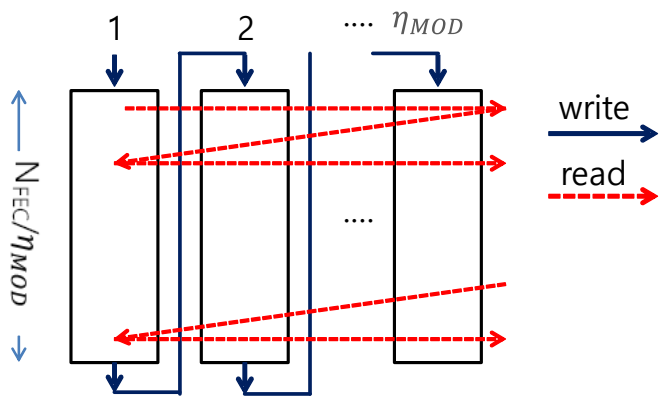


**Figure 6.27** Block interleaving scheme.

Each block interleaved group is demultiplexed bit-by-bit in a group before constellation mapping. Depending on modulation order, there are two mapping rules. In the case of QPSK, the reliability of bits in a symbol is equal. Therefore, a bit group read out from the Block Interleaver shall be mapped directly to a QAM symbol without any intervening operation. In the cases of higher order modulations a bit group shall be mapped to a QAM symbol with the rule described as follows:

$$S_{demux_in}(i) = \{b_i(0), b_i(1), b_i(2), ..., b_i(\eta_{MOD} - 1)\},$$
$$S_{demux_out}(i) = \{c_i(0), c_i(1), c_i(2), ..., c_i(\eta_{MOD} - 1)\},$$
$$c_i(0) = b_i(i\%\eta_{MOD}), c_i(1) = b_i((i+1)\%\eta_{MOD}), ..., c_i(\eta_{MOD} - 1) = b_i((i + \eta_{MOD} - 1)\%\eta_{MOD})$$

where $i$ is the bit group index corresponding to the row index in block interleaving, i.e. output bit group $S_{demux_out}(i)$ to map each QAM symbol is cyclically shifted from $S_{demux_in}(i)$ according to bit group index $i$.

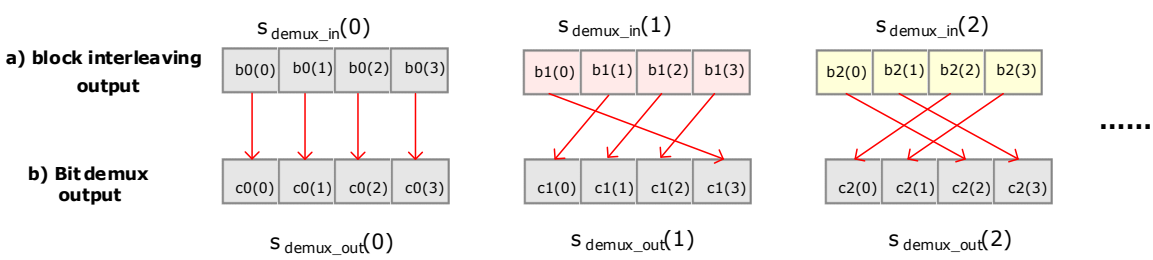


**Figure 6.28** Example of bit demultiplexing rule for 16-NUC.

Figure 6.28 shows an example of the bit demultiplexing rule for 16-NUC.

This operation shall continue until all bit groups have been read from the Block Interleaver.

#### 6.5.2.11 Constellation Mapping

Each demultiplexed LDPC block shall be mapped onto constellation symbols. According to the Mode $S_{demux_output}(i)$ shall be mapped to cells using constellations as described in Section 6.3.

### 6.5.3 L1-Detail Specific Block Details

The following subsections refer to blocks that only occur in the encoding of L1-Detail information.

#### 6.5.3.1 Segmentation

The amount of L1-Detail signaling information bits is variable and depends mainly on the number of subframes and the number of PLPs. Therefore, one or more FEC Frames may be required for transmission of the total amount of signaling. The number of FEC Frames for the L1-Detail signaling, $N_{L1D_FECFRAME}$, shall be determined as follows:

$$N_{L1D_FECFRAME} = \left\lceil \frac{K_{L1D_ex_pad}}{K_{seg}} \right\rceil$$

where $\lceil x \rceil$ means the smallest integer larger than or equal to $x$, $K_{seg}$ for each L1-Detail Mode is defined in Table 6.25 and $K_{L1D_ex_pad}$ shall be determined by the value of the field **L1B_L1_Detail_size_bytes** in L1-Basic signaling, which denotes the length of the L1-Detail signaling (excluding L1 Padding bits), as described in Figure 6.29.

$K_{seg}$ is a threshold number defined for segmentation based on the number of LDPC encoder input information bits ($K_{ldpc}$). $K_{seg}$ causes the number of information bits in a coded block after the segmentation ($K_{sig}$) to be less than or equal to ($K_{ldpc} - M_{outer}$). Here, $K_{ldpc}$ and $M_{outer}$ are given in Table 6.18 and Table 6.19 in Sections 6.5.2.3 and 6.5.2.4, respectively. Note that the value of $K_{seg}$ for L1-Detail Mode 1 is set to ($K_{ldpc} - M_{outer} - 720$) to provide sufficient robustness.

**Table 6.25** $K_{seg}$ for L1-Detail Signaling

| **L1-Detail** | $K_{seg}$ |
|---|---|
| Mode 1 | 2352 |
| Mode 2 | 3072 |
| Mode 3 | 6312 |
| Mode 4 | |
| Mode 5 | |
| Mode 6 | |
| Mode 7 | |

The length of the L1_PADDING field for the L1-Detail signaling, $K_{L1D_PAD}$, shall be calculated as follows:

$$K_{L1D_PAD} = \left\lceil \frac{K_{L1D_ex_pad}}{N_{L1D_FECFRAME} \times 8} \right\rceil \times 8 \times N_{L1D_FECFRAME} - K_{L1D_ex_pad}.$$

The L1_PADDING parts shall be filled with $K_{L1D_PAD}$ zeros. This is illustrated in Figure 6.29. The final length of the whole L1-Detail signaling including the zero-padding bits, $K_{L1D}$ shall be set as follows:

$$K_{L1D} = K_{L1D_ex_pad} + K_{L1D_PAD}.$$

The number of information bits in each of $N_{L1D_FECFRAME}$ blocks, $K_{sig}$ shall then be given by:

$$K_{sig} = \frac{K_{L1D}}{N_{L1D_FECFRAME}}.$$

The L1-Detail signaling shall be segmented into $N_{L1D_FECFRAME}$ blocks when $N_{L1D_FECFRAME}$ is larger than 1, as illustrated in Figure 6.29

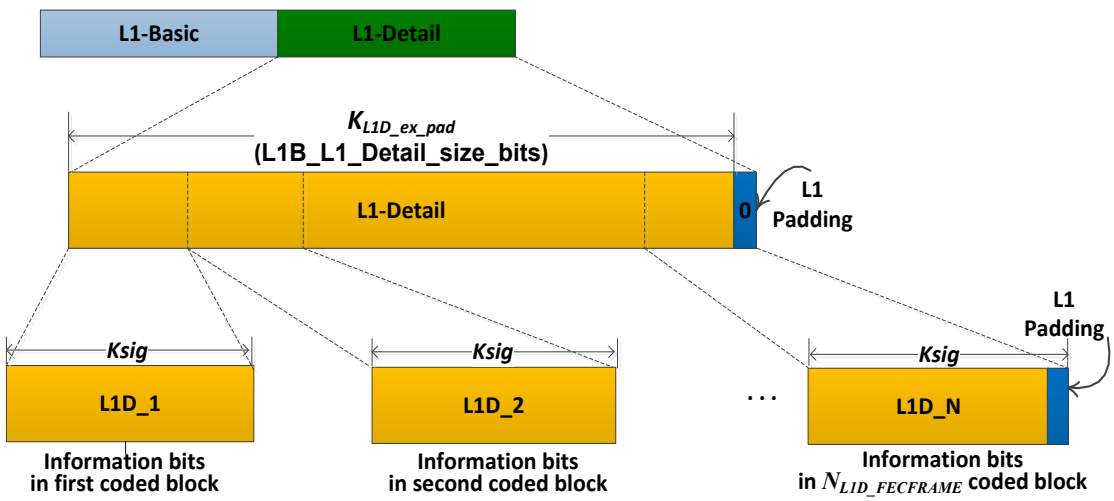


**Figure 6.29** Segmentation of L1-Detail signaling.

Each segmented L1-Detail block shall be protected according to the procedures described in Section 6.5.2. All of the bits of each L1-Detail block with information size of $K_{sig}$ shall be scrambled according to Section 6.5.2.2. Each scrambled L1-Detail signaling block shall then be protected by a concatenation of a BCH Outer Code and an LDPC Inner Code. Each L1-Detail signaling block shall be first BCH-encoded, where $M_{outer}$ (= 168) BCH parity-check bits are appended to $K_{sig}$ information bits of each block. The resulting concatenation of the information bits of each block and the BCH parity bits shall then be protected by a shortened and punctured 16K LDPC code, as described in Sections 6.5.2.8 and 6.5.2.9. When required, repetition shall be applied before puncturing, as described in Section 6.5.2.7.

#### 6.5.3.2 Additional Parity

To increase further the robustness of the L1-Detail signaling, additional parity bits for the L1-Detail signaling of the frame #(*i*) may be transmitted in the closest (in time) previous frame #*(i-1)* that has the same bootstrap major/minor version as does the frame #(*i*). Figure 6.30 shows how additional parity bits for L1-Detail in frame #*(i)* shall be transmitted in the Preamble of frame #(*i-1*).

The use of additional parity bits for L1-Detail of frame *#(i)* with the same major/minor bootstrap version is signaled with **L1B_L1_Detail_additional_parity_mode** in the frame *#(i-1)*. When **L1B_L1_Detail_additional_parity_mode** is set to '00' in frame *#(i-1)*, additional parity for L1-Detail signaling of the frame *#(i)* shall not be transmitted in frame *#(i-1)*.

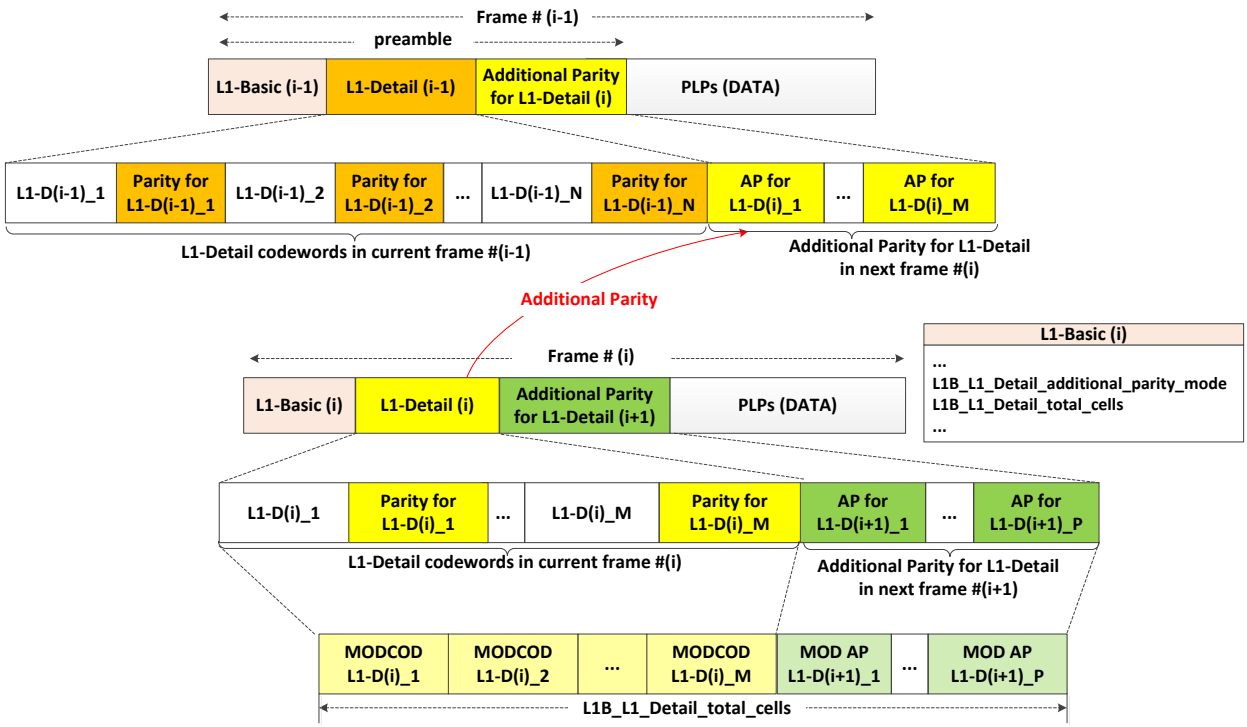


**Figure 6.30** Additional parity for L1-Detail signaling.

The result of using additional parity is diversity gain for the L1 signaling. When the number of punctured bits is larger than the number of additional parity bits, additional parity bits shall be generated by selecting the bits among punctured bits based on puncturing order. Otherwise, additional parity bits shall be generated by selecting all punctured bits and then selecting $(N_{AP} - N_{punc})$ parity bits.

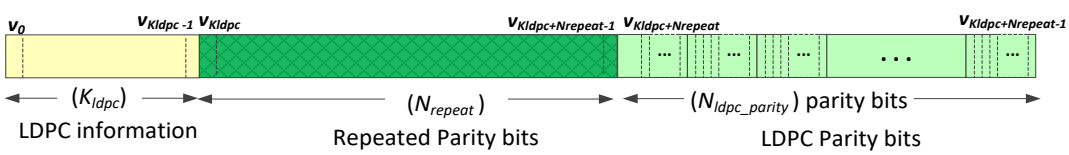


**Figure 6.31** Repeated LDPC codeword.

The number of additional parity bits shall be decided from the total number of transmitted bits in the current frame. Based on the repeated LDPC codeword denoted by $V = (v_0, v_1, \ldots, v_{Ninner+Nrepeat-1})$ as shown in Figure 6.31, additional parity bits shall be generated by the following operations:

**Step 1)** Compute the temporary number of additional parity bits such that

$$N_{AP_temp} = \min\begin{Bmatrix} 0.5 \times K \times \left(N_{outer} + N_{ldpc_parity} - N_{punc} + N_{repeat}\right), \\ \left(N_{ldpc_parity} + N_{punc} + N_{repeat}\right) \end{Bmatrix}, K=0,1,2$$

where $K$ corresponds to the field **L1B_L1_Detail_additional_parity_mode** in L1-Basic and where the operation

$$\min(a,b) = \begin{cases} a, if\ a \le b \\ b, if\ b < a \end{cases}.$$

**L1B_L1_Detail_additional_parity_mode** is the ratio of the number of additional parity bits to half of the total number of bits in the transmitted coded L1-Detail signaling block, which is the L1-Detail signaling block following repetition, puncturing and zero-removal. Note that the value of **L1B_L1_Detail_additional_parity_mode** related to the L1-Detail of frame (#i) is carried in frame (#i-1); that is, the previous frame.

**Step 2**) Derive the number of additional parity bits as the following integer multiple of the modulation order:

$$N_{AP} = \left\lfloor \frac{N_{AP_temp}}{\eta_{MOD}} \right\rfloor \times \eta_{MOD}$$

where the operation $\lfloor x \rfloor$ means the largest integer less than or equal to x and $\eta_{MOD}$ denotes the modulation order taking the value 2, 4, 6, and 8 for QPSK, 16-NUC, 64-NUC and 256-NUC, respectively.

**Step 3**) If $N_{AP} \le N_{punc}$, then punctured parity bits

$$\left(v_{N_{repeat}+N_{inner}-N_{punc}}, v_{N_{repeat}+N_{inner}-N_{punc}+1}, \cdots, v_{N_{repeat}+N_{inner}-N_{punc}+N_{AP}-1}\right)$$

shall be selected for additional parity as shown in Figure 6.32.

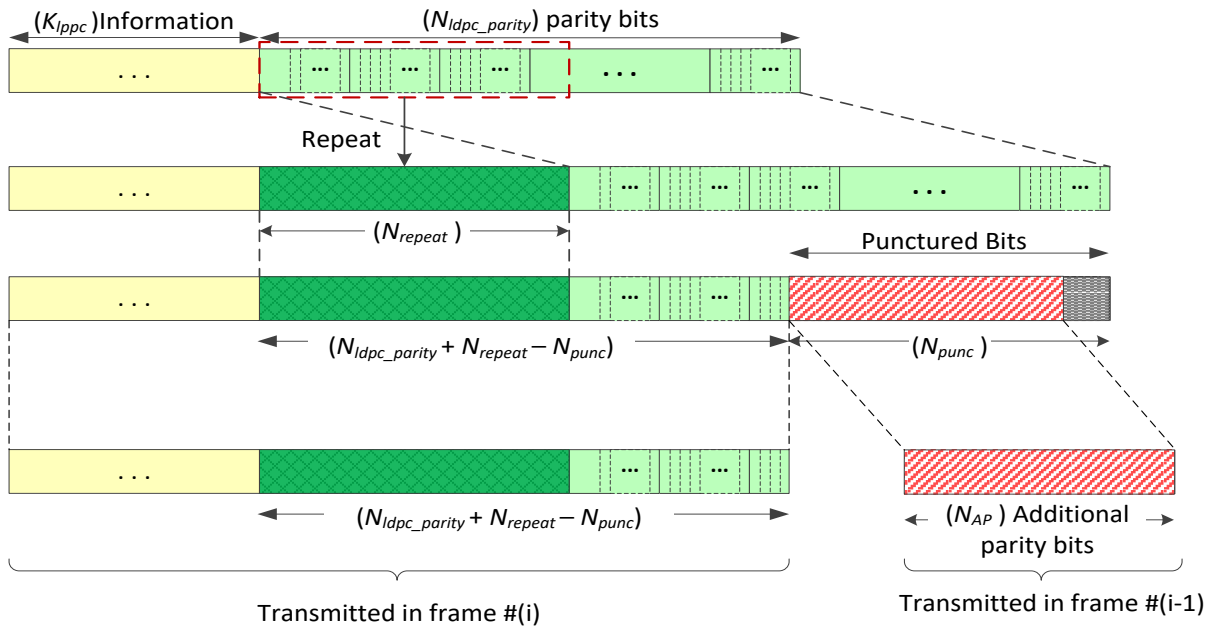


**Figure 6.32** Additional parity generation for L1-Detail signaling ($N_{AP} \leq N_{punc}$).

Otherwise ($N_{AP} > N_{punc}$); therefore all punctured parity bits $\left(v_{N_{repeat}+N_{inner}-N_{punc}}, v_{N_{repeat}+N_{inner}-N_{punc}+1}, \cdots, v_{N_{repeat}+N_{inner}-1}\right)$ shall be selected, and additionally, parity bits $(v_{K_{ldpc}}, v_{K_{ldpc}+1}, \cdots, v_{K_{ldpc}+N_{AP}-N_{punc}-1})$ shall be selected and appended to the punctured bits as shown in Figure 6.33.

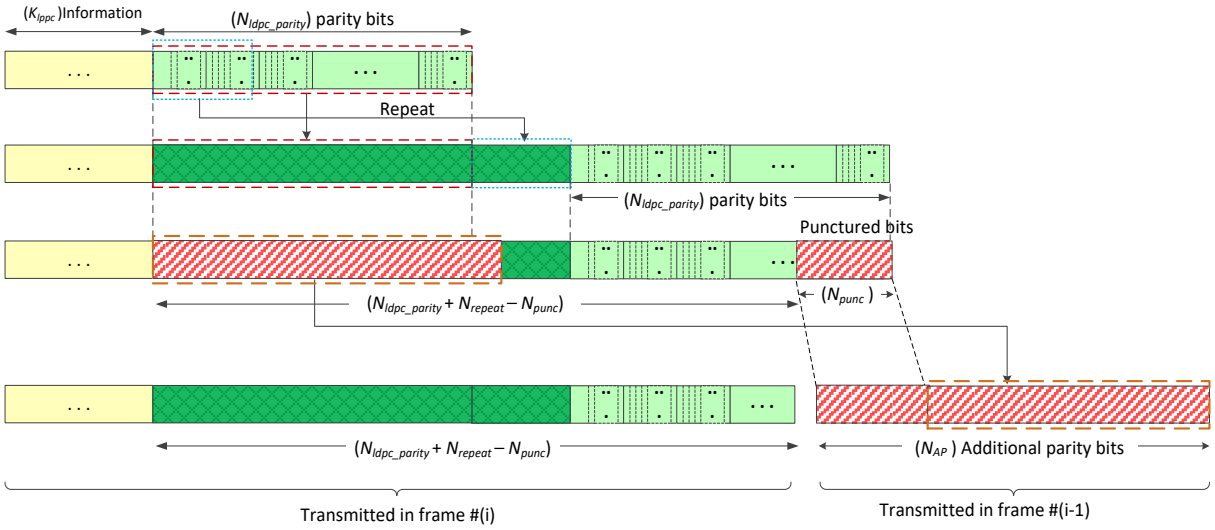


**Figure 6.33** Additional parity generation for L1-Detail signaling ($N_{AP} > N_{punc}$).

Note that the number of bits for repetition, $N_{repeat}$, is 0 for L1-Detail Modes 2, 3, 4, 5, 6 and 7.

The additional parity bits shall be bit-interleaved and mapped onto constellations as described in Sections 6.5.2.10 and 6.5.2.11, respectively. The constellations generated for the additional parity bits shall be generated in the same manner as for the repeated, punctured and zero-removed L1-Detail signaling bits that are transmitted in the current frame. After mapping onto constellations, the additional parity bits shall be appended to coded L1-Detail signaling blocks in the frame preceding the current frame carrying the L1-Detail signaling of current frame, as illustrated in Figure 6.30.

## 7. FRAMING AND INTERLEAVING

The framing and interleaving block consists of three parts: time interleaving, framing and frequency interleaving. The input to the time interleaving and framing blocks consists of one or more PLPs, however the output of the framing block is OFDM symbols, either Preamble, Data, or Subframe Boundary Symbols which are arranged in the order in which they appear in the final frame. The frequency interleaver operates on OFDM symbols. A block diagram of the framing and interleaving is shown in Figure 7.1.

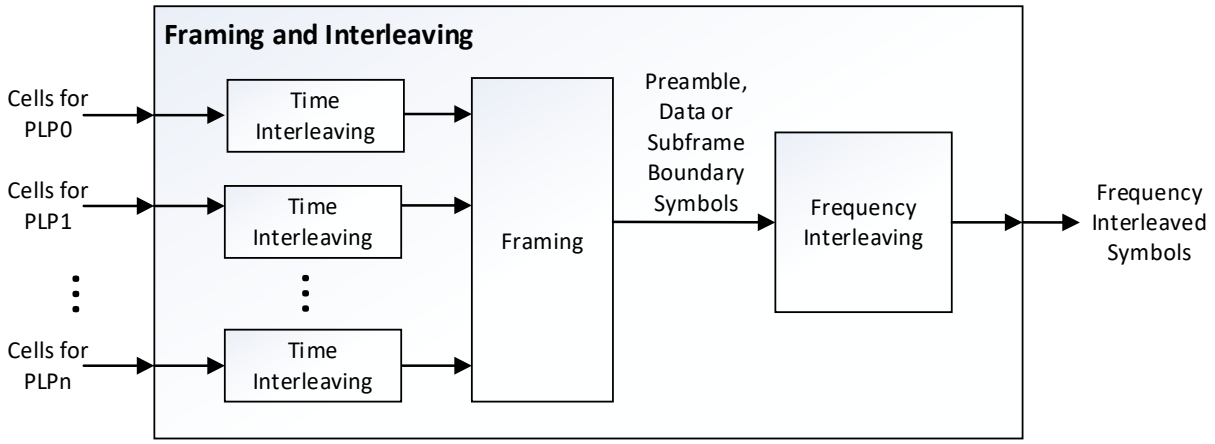


**Figure 7.1** Block diagram of framing and interleaving.

### 7.1 Time Interleaving

The input to the time interleaving block is a stream of cells output from the mapper block, and the output of the time interleaving block is a stream of time-interleaved cells.

#### 7.1.1 Time Interleaver Modes

Each PLP is configured with one of the following time interleaver modes as applicable: no time interleaving, Convolutional Time Interleaver (CTI) mode (see Section 7.1.4), or Hybrid Time Interleaver (HTI) mode (see Section 7.1.5). The time interleaver mode for a PLP is indicated by the L1-Detail signalling field **L1D_plp_TI_mode**. The time interleaver mode indicated for an Enhanced PLP shall be the same as the time interleaver mode indicated for the Core PLP(s) with which the Enhanced PLP is layered division multiplexed.

When, as determined at the input to the time interleaver, a complete delivered product is composed of only a single constant-cell-rate PLP or is composed of a single constant-cell-rate Core PLP and one or more constant-cell-rate Enhanced PLPs layered division multiplexed with that Core PLP, the PLP(s) comprising that complete delivered product shall be configured with one of the following time interleaver modes: no time interleaving, CTI mode, or HTI mode.

When, as determined at the input to the time interleaver, a complete delivered product is composed of PLPs having characteristics different from those described in the preceding paragraph, the PLPs comprising that complete delivered product shall be configured with one of the following time interleaver modes: no time interleaving or HTI mode.

The time interleaver mode(s) for the PLPs of a particular complete delivered product shall be configured independently of the time interleaver mode(s) for the PLP(s) of any other delivered products transmitted within the same RF channel. When a particular delivered product contains multiple Core PLPs and/or PLPs that are not layered division multiplexed, those PLPs may be configured with the same or different time interleaver modes (i.e., no time interleaving and/or HTI mode) and/or the same or different time interleaver parameters.

When a particular complete delivered product contains multiple Core PLPs that are not layered-division multiplexed and all of those Core PLPs use the HTI mode, either all of those Core PLPs shall use intra-subframe interleaving or else all of those Core PLPs shall use inter-subframe interleaving (i.e., all of those Core PLPs shall be configured with the same value of **L1D_plp_HTI_inter_subframe**). When inter-subframe interleaving is used for those Core PLPs (i.e., **L1D_plp_HTI_inter_subframe** = 1), then all of those Core PLPs shall use the same time interleaving unit ($N_{IU}$).

When a particular complete delivered product contains multiple Core PLPs that are not layered-division multiplexed and at least one of those Core PLPs uses the no-TI mode, any of those Core PLPs configured with the HTI mode shall use the intra-subframe interleaving mode (i.e., **L1D_plp_HTI_inter_subframe** = 0).

When time interleaving is not configured for a PLP, that PLP's cells shall be output in the same order as that in which they would have arrived at the input of the time interleaving function and without delay.

### 7.1.2 Time Interleaver Size

The maximum size of the TI memory for a single, complete delivered product shall be $M_{TI}= 2^{19}$ cells, except for extended interleaving mode, for which the maximum size of the TI memory for a single, complete delivered product shall be $M_{TI}= 2^{20}$ cells. The TI memory size shall include all necessary parts; that is, the Convolutional Time Interleaver in CTI mode and the Cell, Twisted Block and Convolutional Delay Line interleavers in HTI mode.

In the CTI mode the entire TI memory may be used by the PLP associated with the particular CTI, depending on the configured depth of the Convolutional Time Interleaver.

In the HTI mode, the total memory shall be shared between PLPs carrying components of the same complete delivered product. The memory allocated for each PLP shall be determined from the throughput for that PLP.

Note that receiver manufacturers can choose always to implement the time deinterleaver memory with $M_{TI}= 2^{19}$ cells, irrespective of the extended time interleaving mode, by quantizing the received data entering the time deinterleaver with a different resolution depending on the robustness of the constellation, that is, lower resolution for QPSK and extended time interleaving, and higher resolution for all other combinations.

### 7.1.3 Extended Interleaving

Extended interleaving mode may be optionally enabled in order to increase the time interleaving depth. Extended interleaving mode is signaled by **L1D_plp_TI_extended_interleaving**. Extended interleaving shall only be used when the modulation is QPSK. Extended interleaving shall not be used for LDM. In the CTI mode when extended interleaving is used, **L1D_plp_CTI_depth**=010 signals

$N_{rows}$ = 1254, and **L1D_plp_CTI_depth**=011 signals $N_{rows}$ = 1448, corresponding to time interleaving depths of approximately 300 ms, and 400 ms, respectively.

When extended interleaving is used in the HTI mode, the number of FEC Blocks per TI Block may be increased. The maximum allowable number of FEC Blocks per TI Block in the extended HTI mode is approximately twice the maximum allowable in the non-extended HTI mode.

### 7.1.4 Convolutional Time Interleaver (CTI) Mode

The time interleaving block for the CTI Mode is shown in Figure 7.2. It consists of a Convolutional Time Interleaver. The input and output of the time interleaving block is a sequence of cells.

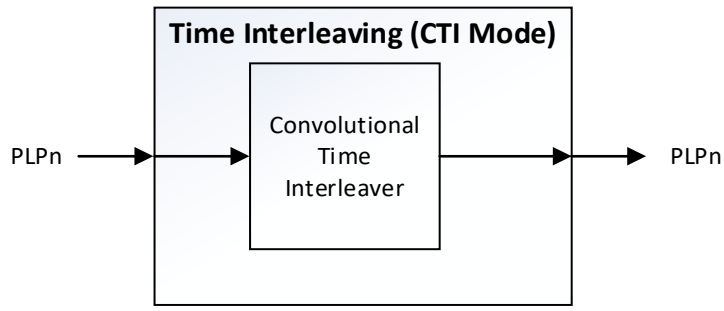


**Figure 7.2** Block diagram for time interleaving for CTI Mode.

#### 7.1.4.1 Convolutional Time Interleaver

The Convolutional Time Interleaver is depicted in Figure 7.3.

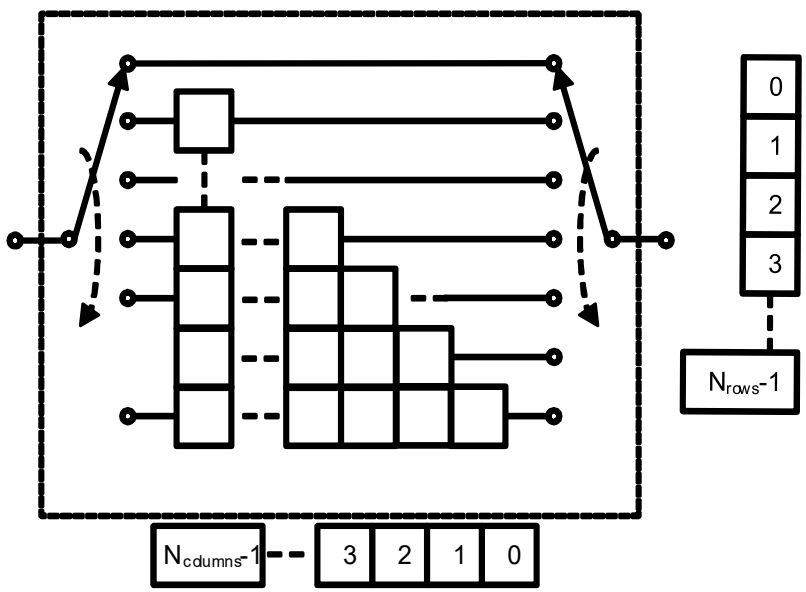


**Figure 7.3** Block diagram of the Convolutional Time Interleaver.

The input to the Convolutional Time Interleaver block shall be a sequence of cells $g_q$ (where $q$ = 0,1,…) from the mapper output. The CTI shall consist of $N_{rows}$ delay lines, with the $k$-th line having $k$ delay elements, $k$ = 0, 1, …, $N_{rows}$-1. Each delay element shall be capable of storing one cell. The number of columns $N_{columns}$ shall be $N_{rows} - 1$. Input and output shall be controlled by two commutators, cyclically switching downwards after one cell is written in or read out, respectively.

For each cell $g_q$, the commutators shall be located at the same row $k$. The resulting total number of delay elements is $N_{rows} \times N_{columns} / 2$.

When the input commutator is located at row $k$, a cell $g_q$ shall be written to this delay line. First, each delay element from this line shall shift its memory content to the neighbouring right delay element, and the content from the right-most delay element shall be output via the output commutator. Next, the input cell $g_q$ shall be written to the left-most delay element of this line. Both commutators shall then move cyclically to the next line $(k+1) \bmod N_{rows}$.

The structures for CTI Mode are defined in terms of the parameter $N_{rows}$, see Table 9.24 for details. The values $N_{rows} \in \{1024, 887, 724, 512\}$ represent time interleaving depths of approximately 200 ms, 150 ms, 100 ms and 50 ms, respectively, assuming the Core PLP occupies the full channel bandwidth. The depth of the Convolutional Time Interleaver, shall be indicated by the parameter **L1D_plp_CTI_depth**.

In contrast to HTI Mode, the CTI Mode TI outputs cells continuously and insertion of dummy modulation values to achieve an integer number of FEC Blocks per subframe is not required, thus reducing the overhead. The position of the commutator at the start of each subframe shall be signaled by **L1D_plp_CTI_start_row** and the position of the start of the first complete FEC Block shall be signaled by **L1D_plp_CTI_fec_block_start**.

#### 7.1.4.2 Initial State of the Delay Elements

For CTI according to Section 7.1.4.1 both with and without extended interleaving according to Section 7.1.3, the initial contents of the delay elements shall be defined as follows:

Since the number of delay elements in the CTI is $N_{rows} \times N_{columns} / 2$, a total number of $\eta_{MOD} \times N_{rows} \times N_{columns} / 2$ bits shall be generated using the same PRBS generator described in Section 5.2.3, starting from the initial state. $\eta_{MOD}$ is the modulation order as defined in Table 6.14, and shall be used according to the chosen modulation of the Core PLP. These bits shall be mapped to QAM cells according to Section 6.3, forming a sequence of cells $g_q$.

The delay elements shall be then filled by $g_q$ from left to right and from top to bottom. This means $g_0$ shall be the initial state of the delay element in row $k = 1$, and $g_1$ shall be the initial state of the left-most delay element in row $k = 2$, while $g_2$ shall be the initial state of the second delay element in this row. In row $k = 3$, the three delay elements from left to right have initial states $g_3$, $g_4$, $g_5$ and so on until the last of these cells forms the initial state of the right-most delay element of the last row, $k = N_{rows} - 1$.

### 7.1.5 Hybrid Time Interleaver (HTI) Mode

The time interleaving for the HTI mode is shown in Figure 7.4, and it consists of a Cell Interleaver, a Twisted Block Interleaver (TBI), and a Convolutional Delay Line (CDL). The input to the Hybrid Time Interleaver is a sequence of cells from the mapper block, and the output is a sequence of time-interleaved cells.

The Cell Interleaver takes input cells in FEC Blocks and arranges them into TI Blocks. A TI Block consists of one or more FEC Blocks. The Cell Interleaver interleaves cells within each FEC Block. The use of the Cell Interleaver is optional and is indicated by the parameter **L1D_plp_HTI_cell_interleaver**.

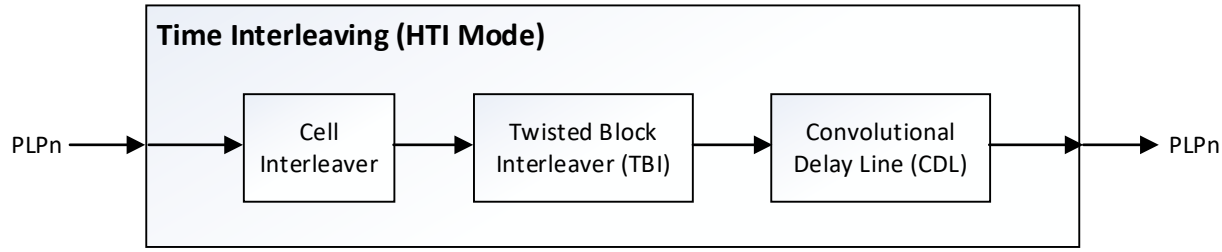


**Figure 7.4** Block diagram for time interleaving for HTI mode.

The Twisted Block Interleaver (TBI) performs intra-subframe interleaving by interleaving TI Blocks. A TI Block is composed of one or more cell-interleaved FEC Blocks (**L1D_plp_HTI_cell_interleaver=1**) or non-cell-interleaved FEC Blocks directly from the mapper block (**L1D_plp_HTI_cell_interleaver=0**).

After block interleaving, the Convolutional Delay Line optionally performs inter-subframe interleaving. When configured, it spreads a block-interleaved TI Block over multiple subframes. The use of the Convolutional Delay Line is signaled with the parameter **L1D_plp_HTI_inter_subframe.**

#### 7.1.5.1 Relationship between IF and TI Blocks

FEC Blocks from the mapper block shall be grouped into interleaving frames (IFs). Note that interleaving frames and physical layer frames (as specified in Section 7.2) are independent constructs. Each IF shall contain a dynamically variable integer number of FEC Blocks. The number of FEC Blocks in the IF of index $n$ is denoted by $N_{BLOCKS_IF}(n)$. $N_{BLOCKS_IF}(n)$ may vary from a minimum value of 1 to a maximum value $N_{BLOCKS_IF_MAX}$. Each IF is either mapped directly onto one subframe or spread out over multiple subframes. Each IF is also divided into one or more TI Blocks, where a TI Block is the basic unit to operate the Cell Interleaver, Twisted Block Interleaver and Convolutional Delay Line. The number of TI Blocks in an interleaving frame, denoted by $N_{TI}$, shall be an integer and is signaled by **L1D_plp_HTI_num_ti_blocks** in conjunction with **L1D_plp_HTI_inter_subframe** (i.e. **L1D_plp_HTI_inter_subframe** = 0). The TI Blocks within an IF may contain slightly different numbers of FEC Blocks. When an IF extends over multiple subframes (i.e. **L1D_plp_HTI_inter_subframe** = 1), then one IF contains exactly one TI Block and $N_{TI} = 1$. The number of FEC Blocks in a TI Block of index $s$ of an interleaving frame $n$ is denoted by $N_{FEC_TI}(n, s)$, where $0 \leq s < N_{TI}$.

When $N_{TI} = 1$, then there will be only one TI Block, with index $s = 0$, per IF and $N_{FEC_TI}(n, s)$ shall be equal to the number of FEC Blocks in the IF, $N_{BLOCKS_IF}(n)$.

When $N_{TI} > 1$, then the value of $N_{FEC_TI}(n, s)$ for each TI Block (index $s$) within the IF (index $n$) shall be calculated as follows:

$$N_{FEC_TI}(n, s) = \begin{cases} \left\lfloor \dfrac{N_{BLOCKS_IF}(n)}{N_{TI}} \right\rfloor & , s < N_{TI} - [N_{BLOCKS_{IF}}(n) \bmod N_{TI}] \\ \left\lfloor \dfrac{N_{BLOCKS_IF}(n)}{N_{TI}} \right\rfloor + 1 & , s \geq N_{TI} - [N_{BLOCKS_{IF}}(n) \bmod N_{TI}] \end{cases}$$

This ensures that the values of $N_{FEC_TI}(n, s)$ for the TI Blocks within an IF differ by at most one FEC Block and that the smaller TI Blocks come first. The FEC Blocks at the input shall be assigned to TI Blocks in increasing order of $s$. $N_{FEC_TI}(n, s)$ may vary in time from a minimum value of 1

to a maximum value $N_{FEC_TI_MAX}$. $N_{FEC_TI_MAX}$ can be determined from $N_{BLOCKS_IF_MAX}$ by the following formula:

$$N_{FEC_TI_MAX} = \left\lceil \frac{N_{BLOCKS_IF_MAX}}{N_{TI}} \right\rceil.$$

Note that $N_{BLOCKS_IF}(n)$ is signaled as **L1D_plp_HTI_num_fec_blocks** and $N_{BLOCKS_IF_MAX}$ is signaled as **L1D_plp_HTI_num_fec_blocks_max.**

#### 7.1.5.2 Cell Interleaver

The input to the Cell Interleaver is a sequence of cells $G(r) = (g_{r,0}, g_{r,1}, g_{r,2}, \cdots, g_{r,Ncells-1})$, arranged in FEC Blocks, where $r$ represents the incremental index of a FEC Block within a TI Block and shall be reset to zero at the beginning of each TI Block. $N_{cells}$ indicates the FEC Block length and is determined by $N_{ldpc}/\eta_{MOD}$ (see Table 6.14).

Figure 7.5 shows the cell interleaving operation; cell interleaving shall be accomplished by writing a FEC Block into memory and reading the FEC Block pseudo-randomly according to the method described below. The permutation sequence varies every FEC Block within a TI Block. Each permutation sequence shall be determined by shifting one pseudo random sequence differently.

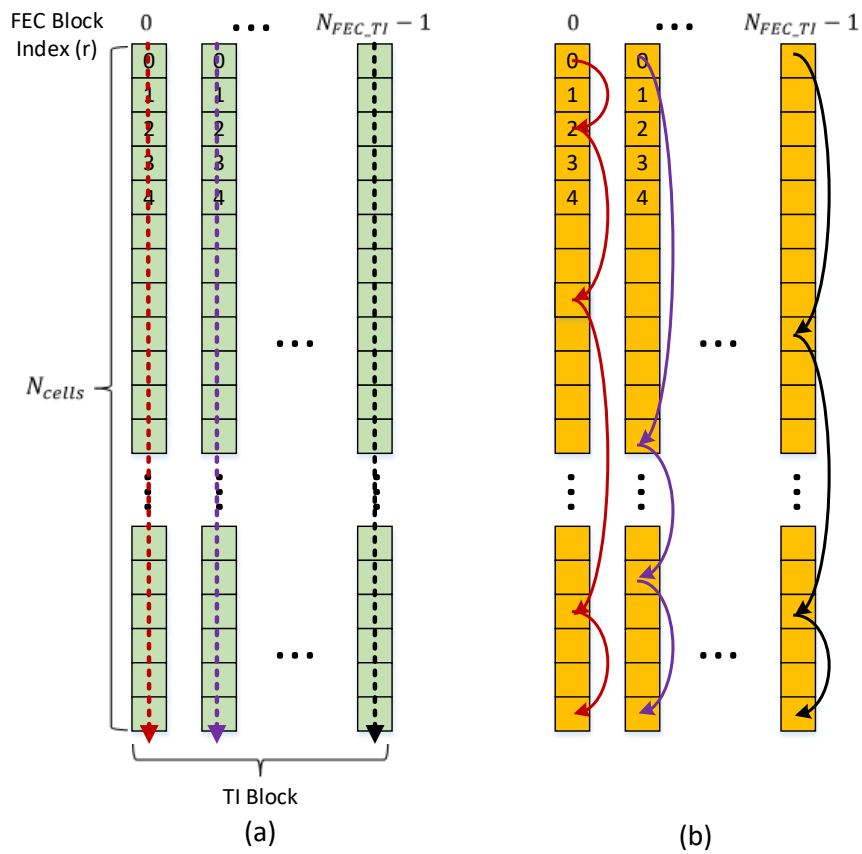


**Figure 7.5** Block diagram of the Cell Interleaver: (*a*) Linear writing operation, (*b*) Pseudo-random reading operation.

From Figure 7.5 the output of the Cell Interleaver shall be a vector $D(r) = (d_{r,0}, d_{r,1}, d_{r,2}, \cdots, d_{r,Ncells-1})$ with $d_{r,q}$, defined by

$$d_{r,q} = g_{r,L_r(q)} \text{ for each } q = 0,1,\cdots,N_{cells} - 1,$$

$L_r(q)$ is a permutation function applied to the $r$-th FEC Block of the TI Block and is given by

$$L_r(q) = [L_0(q) + P(r)] \bmod N_{cells}$$

where $L_0(q)$ is the basic permutation function (typically for the first FEC Block of a TI Block) and $P(r)$ is the shift value to be used in the $r$-th FEC Block of the TI Block.

A constant shift (modulo $N_{cells}$) shall be added to the basic permutation in order to generate a different interleaving sequence over each FEC Block.

The basic permutation function $L_0(q)$ is defined by the following algorithm.

An $N_d$-bit binary word $S_i$ is defined as follows:

For all $i$: $S_i[N_d - 1] = (i \bmod 2)$,

For $i = 0,1$: $S_i[N_d - 2, N_d - 3, \cdots, 1,0] = [0,0,\cdots,0,0]$,

For $i = 2$: $S_2[N_d - 2, N_d - 3, \cdots, 1,0] = [0,0,\cdots,0,1]$,

For $2 < i < 2^{N_d}$: $S_i[N_d - 3, N_d - 4, \cdots, 1,0] = S_{i-1}[N_d - 2, N_d - 3, \cdots, 2,1]$,

for $N_d = 11$: $S_i[9] = S_{i-1}[0] \oplus S_{i-1}[3]$,

for $N_d = 12$: $S_i[10] = S_{i-1}[0] \oplus S_{i-1}[2]$,

for $N_d = 13$: $S_i[11] = S_{i-1}[0] \oplus S_{i-1}[1] \oplus S_{i-1}[4] \oplus S_{i-1}[6]$,

for $N_d = 14$: $S_i[12] = S_{i-1}[0] \oplus S_{i-1}[1] \oplus S_{i-1}[4] \oplus S_{i-1}[5] \oplus S_{i-1}[9] \oplus S_{i-1}[11]$,

for $N_d = 15$: $S_i[13] = S_{i-1}[0] \oplus S_{i-1}[1] \oplus S_{i-1}[2] \oplus S_{i-1}[12]$,

where $N_d = \lceil \log_2 N_{cells} \rceil$. The sequence $L_0(q)$ is then generated by discarding values of $S_i$ greater than or equal to $N_{cells}$ as defined in the following algorithm:

```
q = 0;
for (i = 0; i < 2^{N_d}; i = i + 1)
{
        L_0(q) = Σ_{j=0}^{N_d-1} S_i(j) 2^j;
        if (L_0(q) < N_cells), q = q + 1;
}
```

The shift value $P(r)$ to be applied in the $r$-th FEC Block is the conversion to decimal of the bit-reversed value of a counter $k$ in binary notation over $N_d$ bits. The counter is incremented if the bit-reversed value is too large.

$k = 0;$
for $\left(r = 0; r < N_{FEC_TI}(n,s); r++\right)$
{
$P(r) = N_{cells};$
while $(P(r) \geq N_{cells})$
{
$P(r) = \sum_{j=0}^{N_d-1} \left\lfloor \frac{k - \left\lfloor \frac{k}{2^{j+1}} \right\rfloor 2^{j+1}}{2^j} \right\rfloor 2^{N_d-1-j};$
$k = k + 1;$
}
}

where $N_{FEC_TI}(n,s)$ is the number of FEC Blocks in TI Block index $s$ of interleaving frame $n$. For example, under the condition of $N_{cells} = 10800$ and $N_d = 14$, the shift value $P(r)$ to be added to the basic permutation (for $r = 0,1,2,3$, etc.) would be 0, 8192, 4096, 2048, 10240, 6144, 1024, 9216, etc.

#### 7.1.5.3 Joint Operation of Twisted Block Interleaver and Convolutional Delay Line in HTI Mode

As a joint operation of the Twisted Block Interleaver (TBI) and Convolutional Delay Line (CDL) Figure 7.6 depicts an operational example.

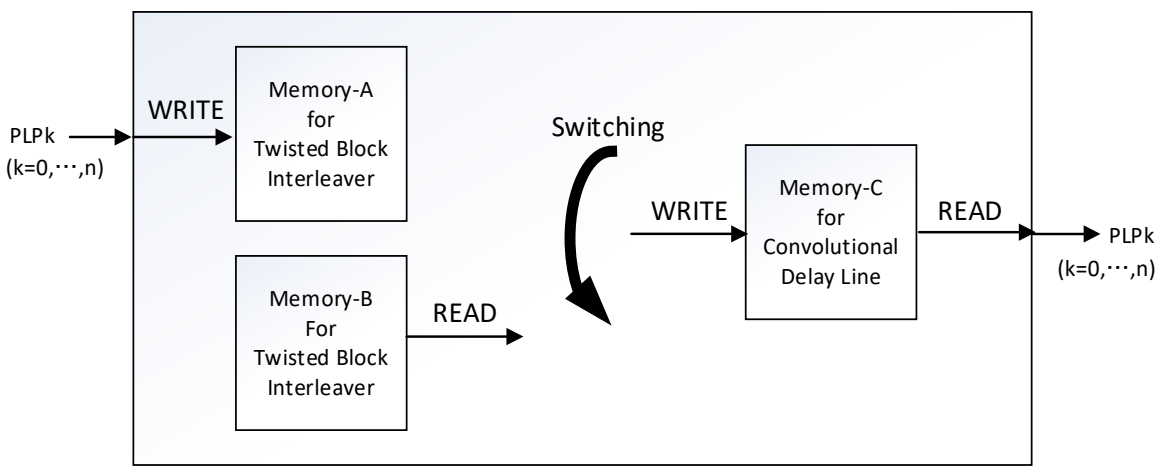


**Figure 7.6** Example of joint operation of TBI and CDL in the HTI.

For each PLP, the first TI Block is written to the first memory for the Twisted Block Interleaver. The second TI Block is written to the second memory for the Twisted Block Interleaver while the first memory is being read. Simultaneously, the read-out TI Block (intra-subframe interleaved TI Block) from the first memory is delivered to the memory for the convolutional interleaver through a first-in-first-out shift register (FIFO) process and so on. For intra-subframe interleaving only the Twisted Block Interleaver is used, while for inter-subframe interleaving both the Twisted Block Interleaver and convolutional interleaver are operated jointly.

#### 7.1.5.4 Twisted Block Interleaver

In the interleaving of each TI Block, the TBI shall store in its memory (one per PLP) the cells $d_{n,s,0,0}, d_{n,s,0,1}, \ldots, d_{n,s,0,N_{cells-1}}$, $d_{n,s,1,0}, d_{n,s,1,1}, \ldots, d_{n,s,N_{FEC_TI}(n,s)-1,0}$, $d_{n,s,N_{FEC_TI}(n,s)-1,1}$, $\ldots$, $d_{n,s,N_{FEC_TI}(n,s)-1,N_{cells-1}}$ of the $N_{FEC_TI}(n,s)$ FEC Blocks from the output of the Cell Interleaver, where $d_{n,s,r,q}$ is the output cell from the Cell Interleaver, belonging to TI Block $s$ in interleaving frame $n$.

In the Twisted Block Interleaver, the number of rows $N_r$ shall be equal to the number of cells in a FEC Block while the number of columns $N_c$ shall be set to $N_{FEC_TI_MAX}$. A graphical representation of the Twisted Block Interleaver is shown in Figure 7.7. Additionally, in the interleaving operation, the concept of a virtual FEC Block is defined and the number of virtual FEC Blocks in a TI Block is denoted by $N_{FEC_TI_Diff}(n,s) = N_{FEC_TI_MAX} - N_{FEC_TI}(n,s)$. Note that any virtual FEC Blocks that are included in a TI Block shall be ahead of data FEC Blocks in the same TI Block for the interleaving in a given memory. A non-zero value of $N_{FEC_TI_Diff}(n,s) \neq 0$ indicates that the number of FEC Blocks (or columns) varies between TI Blocks depending on the cell rate.

The FEC Blocks shall be serially written column-wise into the Twisted Block Interleaver memory part as shown in Figure 7.7(a), where it is generally assumed that $N_{FEC_TI_Diff}(n,s) \neq 0$. Then, cells shall be read out diagonal-wise from the first row (rightwards along the row beginning with the left-most column) to the last row out as shown in Figure 7.7(b). During the reading process, virtual cells belonging to virtual FEC Blocks shall be skipped.

In a block interleaving array, the diagonal-wise reading can be performed by calculating the position for data and virtual cells with a coordinate $(R_i, C_i)$ (for $i = 0, \cdots, N_r N_c - 1$):

$$R_i = i \bmod N_r,$$

$$T_i = R_i \bmod N_c,$$

$$C_i = \left(T_i + \left\lfloor \frac{i}{N_r} \right\rfloor\right) \bmod N_c,$$

where $R_i$ and $C_i$ indicate the row and column indexes, respectively, and $T_i$ is a twisting parameter. Assuming cells are read out sequentially from a linear memory array, the cell position can be calculated as $\theta_i = N_r C_i + R_i$. Note that virtual cells shall be skipped during the reading process if the condition of $\theta_i \geq N_{FEC_TI_Diff}(n,s) \cdot N_r$ is not satisfied.

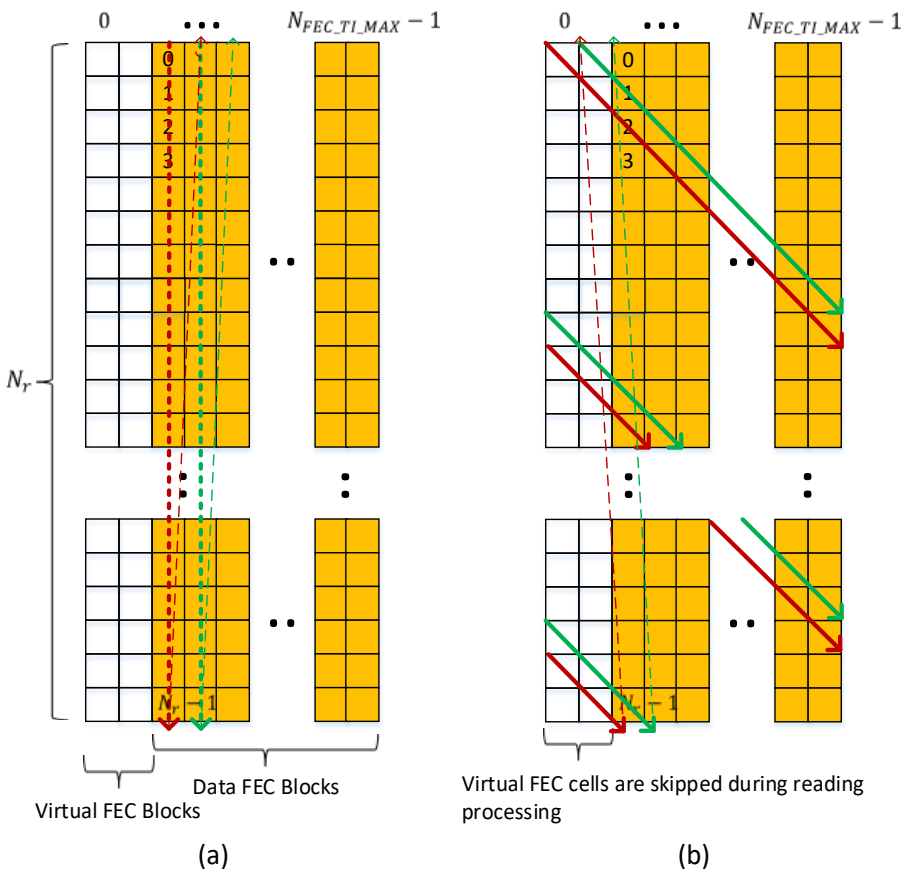


**Figure 7.7** Block diagram of Twisted Block Interleaver: (*a*) linear writing operation, (*b*) diagonal-wise reading operation.

#### 7.1.5.5 Convolutional Delay Line

The Convolutional Delay Line spreads FEC Blocks over multiple subframes in order to realize inter-subframe interleaving. The block diagram of the CDL is shown in Figure 7.8. The delay-line consists of $N_{IU}$ branches, which split a TI Block into $N_{IU}$ interleaving units and spread these interleaving units over $N_{IU}$ subframes. To this end, each branch is connected to a sequence of FIFO registers acting as delay elements. The number of cells which a FIFO register can store maximally is denoted as $M_{i,j}$. The top branch does not contain any FIFO register; each lower branch adds an additional FIFO register.

The FIFO register sizes shall be obtained as follows:

- $L_{\mathrm{IU}} = \mathrm{floor}(N_r/N_{IU})$, where floor($x$) is the largest integer $\leq x$.
- Each FIFO register present in the first $N_{\mathrm{large}} = N_{\mathrm{r}} \bmod N_{\mathrm{IU}}$ branches (this includes the first branch of the CDL which does not contain any FIFO registers) shall contain $M_{i,j} = (L_{\mathrm{IU}} + 1) \cdot N_{FEC_TI_MAX}$ cells. Here mod represents the modulo-operation.
- Each FIFO register present in the following $N_{small} = N_{\mathrm{IU}} - N_{\mathrm{large}}$ branches shall contain $M_{i,j} = L_{\mathrm{IU}} \cdot N_{FEC_TI_MAX}$ cells.

All FIFO registers contain exactly $L_{\mathrm{IU}} \cdot N_{FEC_TI_MAX}$ cells for the case when $N_{\mathrm{r}}$ is an integer multiple of $N_{\mathrm{IU}}$ such that $N_{\mathrm{large}} = 0$. The number of columns in the Twisted Block Interleaver, $N_{FEC_TI}(n, s)$, may change between TI Blocks.

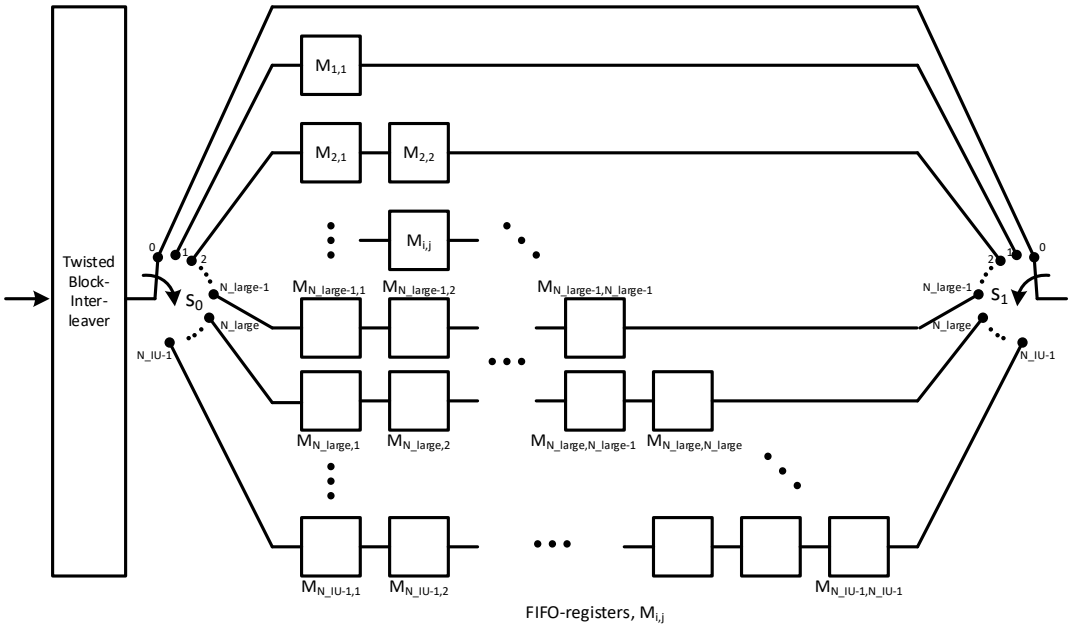


**Figure 7.8** Block diagram of Convolutional Delay Line used in the HTI.

Switch $s_0$ connects the TBI to the CDL. Switch $s_1$ connects the CDL to the framing block. The movement of the switches shall be synchronized; i.e., they shall always point to identical branches of the CDL. From the last branch of the CDL the switches shall then move back to the first branch of the CDL. Both switches ($s_0$ and $s_1$) shall move from branch $n$ of the CDL to the immediately subjacent branch $n$+1 of the CDL when $N_{FEC_TI_MAX}$ cells, consisting of $N_{FEC_TI}(n,s)$ data cells and ($N_{FEC_TI_MAX}$ - $N_{FEC_TI}(n,s)$) virtual cells, are written to the CDL. Both switches ($s_0$ and $s_1$) shall be reset to the first branch of the CDL (i.e., branch 0) at the start of every subframe. Virtual cells shall not be read from the TBI and shall not be passed on to the CDL. However, after each row of $N_{FEC_TI}(n,s)$ data cells is written from the TBI to the CDL (as described in Section 7.1.5.4), a set of ($N_{FEC_TI_MAX}$ - $N_{FEC_TI}(n,s)$) new virtual cells for the CDL shall then be input to the CDL prior to switches $s_0$ and $s_1$ moving to the next branch of the CDL. Virtual cells shall not be written to the HTI output, neither from the TBI nor from the CDL.

$N_{FEC_TI_MAX}$ corresponds to the maximum number of columns of the Twisted Block Interleaver. Hence, the switches $s_0$ and $s_1$ change their position every time a row from the Twisted Block Interleaver has been read.

The total number of cells contained in the HTI amounts to $M_{HTI} = N_r + 0.5 \times N_{FEC_TI_MAX} \times \left(2N_r + (L_{IU} + 1)N_{large}\left(N_{large} - 1\right) + L_{IU}\left(N_{IU}(N_{IU} - 1) - N_{large}\left(N_{large} - 1\right)\right)\right)$ for the case that $N_r$ is not an integer multiple of $N_{IU}$, which simplifies to $N_r + 0.5 \times N_{FEC_TI_MAX} \times N_r \times (N_{IU} + 1)$ for the case that $N_r$ is an integer multiple of $N_{IU}$.

#### 7.1.5.6 HTI Options

In HTI mode there are two basic options that can be selected, intra-subframe interleaving and inter-subframe interleaving.

- Intra-subframe interleaving: Each interleaving frame is mapped directly to one subframe and the interleaving frame is composed of one or more TI Blocks as shown in Figure 7.9 on the left-hand side. Each of the TI Blocks can be de-interleaved and decoded immediately after its complete reception in the receiver. This allows the maximum bit-rate for the PLP to be increased. This option is signaled as **L1D_plp_HTI_inter_subframe** = 0. For this option, the number of TI Blocks per interleaving frame is set to $N_{TI}$ = **L1D_plp_HTI_num_ti_blocks+1**, and $N_{IU} = 1$.
- Inter-subframe interleaving: Each interleaving frame contains one TI Block and is mapped to multiple subframes. Figure 7.9 shows on the right-hand side an example in which one interleaving frame is mapped onto two subframes. This gives greater time diversity for low data-rate services. This option is signaled in the L1 signaling by **L1D_plp_HTI_inter_subframe** = 1. For this option, the number of TI Blocks per interleaving frame is set to $N_{TI}$ = 1, and $N_{IU}$= **L1D_plp_HTI_num_ti_blocks+1**.

Observe that in case of **L1D_plp_HTI_num_ti_blocks** being set to 0 (i.e. $N_{TI}$ = 1), each interleaving frame contains one TI Block and is mapped directly to one subframe, irrespective of the value of **L1D_plp_HTI_inter_subframe** (in the middle of Figure 7.9 ).

Note that the HTI in its entirety; i.e., including Cell Interleaver, Twisted Block Interleaver, and Convolutional Delay Line, shall not be in use when **L1D_plp_TI_mode** = '00' (see Table 9.21).

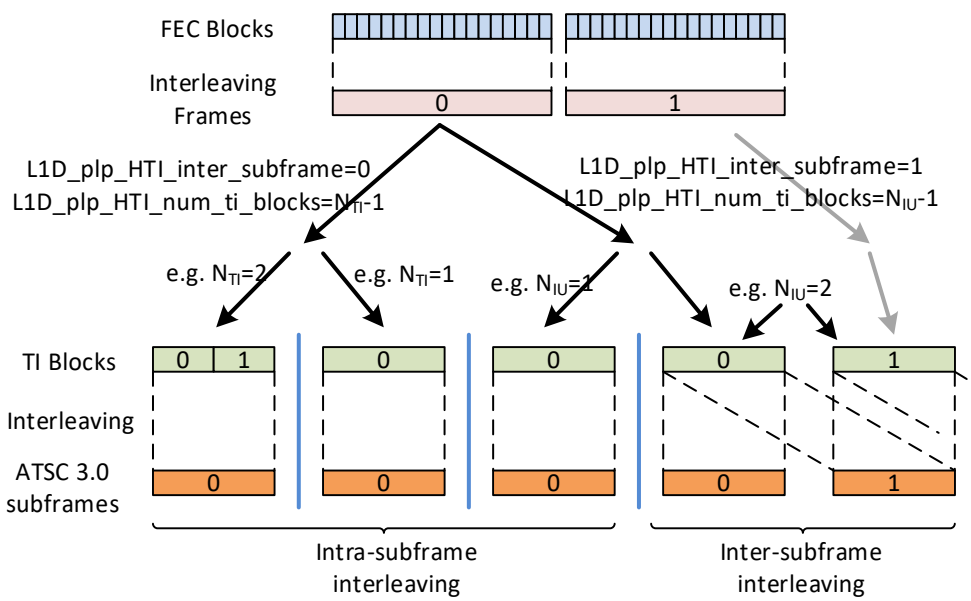


**Figure 7.9** Example of HTI for **L1D_plp_HTI_inter_subframe** = 0 and 1, and for **L1D_plp_HTI_num_ti_blocks** = 0 and 1.

#### 7.1.5.7 Initial State of the HTI's CDL for Inter-Subframe Interleaving

For HTI with inter-subframe interleaving, the initial contents of the HTI memory (i.e., the CDL) shall be defined as follows.

Define $M_{CDL} = \left(N_{IU}(N_{IU}-1)L_{IU} + N_{large}\left(N_{large}-1\right)\right)/2$. A total number of $\eta_{MOD} \times M_{CDL}$ bits shall be generated using the same PRBS generator described in Section 5.2.3, starting from the initial state. $\eta_{MOD}$ is the modulation order as defined in Table 6.14, and shall be used according to the chosen modulation of the respective PLP. These bits shall be mapped to QAM cells according to Section 6.3, forming a sequence of $M_{CDL}$ initialization cells $g_q$. The initialization cells $g_q$ shall be input in order directly into the CDL according to the following procedure.

- Initialization cell inputs shall begin with the first delay branch (i.e., branch 1). No initialization cells shall be input to branch 0.
- Immediately after each initialization cell is input to the current branch of the CDL, $N_{FEC_TI_MAX} - 1$ virtual cells shall be input to the same branch of the CDL.
- Branch $i$ of the CDL shall receive:
  - 0 initialization cells if $i = 0$
  - $i \times (L_{IU} + 1)$ initialization cells if $N_{large} > 0$ and $0 < i < N_{large}$
  - $i \times L_{IU}$ initialization cells if $N_{large} > 0$ and $N_{large} \leq i < N_{IU}$
  - $i \times L_{IU}$ initialization cells if $N_{large} = 0$ and $0 < i < N_{IU}$
- Each branch of the CDL shall receive all of its initialization cells before moving on to the next branch of the CDL.

When a CDL in an HTI is initialized, interleaving frame 0 for the corresponding PLP shall be considered to begin in the first subframe of actual transmission for the PLP following HTI initialization. All interleaving frames for that PLP that are considered to begin in subframes prior to that first subframe of actual transmission shall be considered to contain a TI block that contains exactly one FEC Block (i.e., $N_{FEC_{TI}}(n,s) = 1$ for $-N_{IU} < n < 0$ and $s = 0$).

## 7.2 Framing

### 7.2.1 Overview

The framing block takes inputs from one or more physical layer pipes in the form of data cells, and outputs frame symbols. Frame symbols represent a set of frequency domain content prior to optional frequency interleaving, followed by pilot insertion, and then conversion to a time domain OFDM symbol via an IFFT and guard interval insertion.

### 7.2.2 Frame Structure

#### 7.2.2.1 Frame Components

A frame shall consist of a combination of three basic components as shown in Figure 7.10.

- One bootstrap, located at the beginning of each frame. The bootstrap shall be created as described in [2]. Further details of the bootstrap are described in Section 8.6. The exact time period from the start of a bootstrap to the start of the next bootstrap that matches the same major and minor bootstrap versions shall be an integer multiple of the sample time of the baseband sampling rate indicated by the first bootstrap.
- One Preamble, located immediately following the bootstrap. The Preamble shall contain L1 control signaling applicable to the remainder of the frame. The Preamble is described in detail in Section 7.2.5.

- One or more subframes shall be located immediately following the Preamble. If multiple subframes are present in a frame, then those subframes shall be concatenated together in time as shown in Figure 7.10.

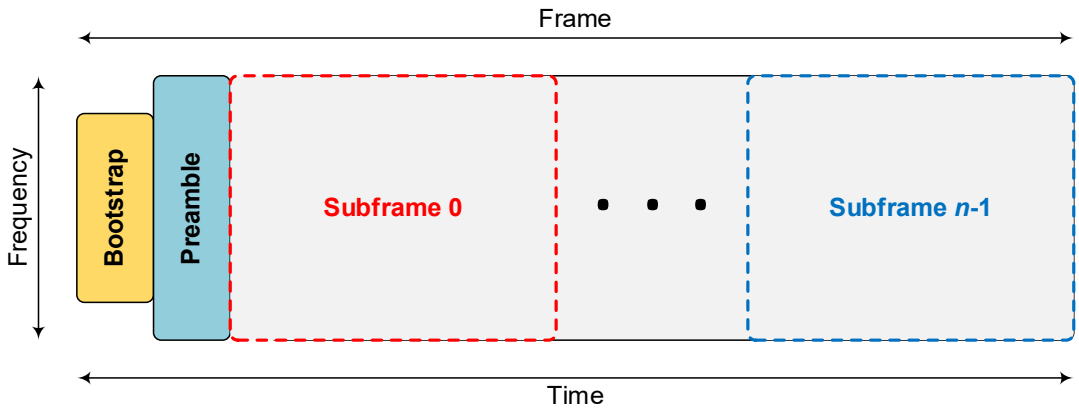


**Figure 7.10** Frame structure.

A subframe shall consist of a set of time-frequency resources within a frame. A subframe shall span the full range of configured carriers in the frequency dimension and shall consist of an integer number of OFDM symbols in the time dimension. The waveform attributes of a subframe constitute a *subframe type*, with those waveform attributes defined as: the FFT size, the GI length, the scattered pilot pattern, the number of useful carriers (*NoC*), whether or not frequency interleaving is enabled for the subframe, and whether the subframe is SISO, MISO, or MIMO. When a subframe is configured for MISO, the waveform attributes defining the subframe type of that subframe additionally shall include the number of transmitters ($N_{TX} \in \{2,3,4\}$) and the time domain span of the filters ($N_{MISO} \in \{64,256\}$). A subframe's waveform attributes shall remain fixed over the duration of that subframe. A frame may contain multiple subframes of the same subframe type and/or multiple subframes of different subframe types. Subframes within the same frame may have different numbers of OFDM symbols. The FFT size and the signaled GI length of the Preamble and the FFT size and the signaled GI length of the first subframe of a frame shall be the same.

A particular PLP shall be mapped only to subframes of the same subframe type. When a PLP is time-interleaved across multiple subframes within an RF channel, those subframes shall be of the same subframe type and may be located in the same frame and/or different frames. Note that this means there may be more subframes in a frame than PLPs, indeed the number of subframes in a frame may exceed the maximum number of PLPs, however the maximum number of PLPs is as defined in Section 5.1.1, regardless of the number of subframes in a frame.

#### 7.2.2.2 Frame Duration

The duration of a frame shall be specified in one of two ways, time-aligned or symbol-aligned.

A time-aligned frame shall use the signaled guard interval length for each subframe within the frame to define a minimum guard interval length for each non-Preamble OFDM symbol within a frame. An overall frame length shall be signaled for a time-aligned frame, where the frame length shall be equal to the sum of the lengths of the bootstrap, the Preamble and the subframe(s) contained within the frame. A time-aligned frame can be recognized by signaling of **L1B_frame_length_mode**=0.

A symbol-aligned frame shall use the signaled guard interval lengths for OFDM symbols and shall not insert any extra samples into any guard intervals within the frame or into any other portions of the frame. A symbol-aligned frame can be recognized by signaling of **L1B_frame_length_mode**=1.

The maximum duration of a frame shall be 5s. The minimum duration of a frame shall be 50 ms.

#### 7.2.2.3 Subframe Duration

The minimum duration of a subframe shall be the greater of 20ms or the duration in ms of $4 \times D_Y$ data and subframe boundary symbols of that subframe. At least $4 \times D_Y$ data and subframe boundary symbols shall be present in every subframe.

### 7.2.3 Number of Carriers

The number of carriers $NoC$ shall be defined by the equation $NoC = NoC_{max} - C_{red_coeff} \times C_{unit}$ where $C_{red_coeff}$ is a positive integer indicating a coefficient to multiply by a control unit value to determine the number of carriers to be reduced. $C_{red_coeff}$ ranges from 0 to 4 and is signaled using the parameters **L1B_preamble_reduced_carriers**, **L1B_first_sub_reduced_carriers**, and **L1D_reduced_carriers** for the Preamble symbols following the first Preamble symbol, the first subframe of the frame, and the second and subsequent subframes of the frame, respectively. The maximum number of carriers in a symbol is denoted by $NoC_{max}$. The control unit $C_{unit}$ takes a value of 96 for 8K FFT, 192 for 16K FFT and 384 for 32K FFT, respectively.

Note that the active relative carrier indices for a particular configuration will range from 0 to $NoC_{max} - C_{red_coeff} \times C_{unit} - 1$, while the active absolute carrier indices for the same configuration will range from $C_{red_coeff} \times C_{unit}/2$ to $NoC_{max} - C_{red_coeff} \times C_{unit}/2 - 1$.

Table 7.1 shows the values for $NoC$ for various values of $C_{red_coeff}$. The value of $NoC_{max}$ can be inferred from the table when $C_{red_coeff}=0$, that is 6913 for 8K FFT, 13825 for 16K FFT and 27649 for 32K FFT.

**Table 7.1** Number of Carriers *NoC* and Occupied Bandwidth

| $C_{red_coeff}$ | Number of Carriers (NoC) | | | Occupied Bandwidth | | |
|---|---|---|---|---|---|---|
| | **8K FFT** | **16K FFT** | **32K FFT** | **bsr_coefficient = 2** | **bsr_coefficient = 5** | **bsr_coefficient = 8** |
| 0 | 6913 | 13825 | 27649 | 5.832844 | 6.804984 | 7.777125 |
| 1 | 6817 | 13633 | 27265 | 5.751844 | 6.710484 | 7.669125 |
| 2 | 6721 | 13441 | 26881 | 5.670844 | 6.615984 | 7.561125 |
| 3 | 6625 | 13249 | 26497 | 5.589844 | 6.521484 | 7.453125 |
| 4 | 6529 | 13057 | 26113 | 5.508844 | 6.426984 | 7.345125 |

### 7.2.4 Frame Symbol Types

Each subframe shall consist of a combination of the following types of symbols in the stated order from the beginning of the subframe to the end of the subframe.

- Subframe boundary symbol (zero or one)
- Data symbols
- Subframe boundary symbol (zero or one)

Note that subframe boundary symbols may not be present in a subframe, and that a subframe may consist of only data symbols.

#### 7.2.4.1 Subframe Boundary Symbols

Subframe boundary symbols shall have a greater scattered pilot density than do data symbols in order to facilitate accurate channel estimation at a receiver.

The first symbol of a subframe shall always be a subframe boundary symbol except when either of the following conditions is satisfied, in which case the first symbol of the subframe may optionally be configured as a subframe boundary symbol.

- The subframe is immediately preceded by a Preamble symbol **and** the Preamble symbol and subframe use the same subframe type waveform attributes (as defined in Section 7.2.2.1) excluding the attribute of whether or not frequency interleaving is enabled (i.e., the frequency interleaver enabled/disabled settings for the Preamble and the subframe are not required to be the same).
- The considered subframe is immediately preceded by another subframe within the same frame **and** both subframes have the same subframe type (as defined in Section 7.2.2.1) excluding the attribute of whether or not frequency interleaving is enabled **and** the last symbol of the preceding subframe is a subframe boundary symbol.

The last symbol of a subframe shall always be a subframe boundary symbol except when the following condition is satisfied, in which case the last symbol of the subframe may optionally be configured as a subframe boundary symbol.

- The considered subframe is immediately followed by another subframe within the same frame **and** both subframes have the same subframe type (as defined in Section 7.2.2.1) excluding the attribute of whether or not frequency interleaving is enabled **and** the first symbol of the following subframe is a subframe boundary symbol.

The presence or absence of a subframe boundary symbol at the beginning and end of each subframe shall be explicitly signaled.

#### 7.2.4.2 Data Symbols

A data symbol shall have a scattered pilot density according to the scattered pilot pattern that is indicated in the control signaling for the corresponding subframe.

The following condition shall be satisfied when the FFT size for a subframe is 32K:

- The sum of the number of data and subframe boundary symbols present in the subframe shall always be even, except for the first subframe of a frame where the sum of the number of Preamble, subframe boundary and data symbols shall be even.

When present at the beginning of a subframe, a subframe boundary symbol shall immediately precede any data symbols for the same subframe.

When present at the end of a subframe, a subframe boundary symbol shall immediately follow the last data symbol for the same subframe.

### 7.2.5 Preamble

The Preamble shall consist of one or more Preamble symbols, which carry the L1 signaling data for the frame.

#### 7.2.5.1 Preamble Symbol(s)

The FFT size, guard interval and scattered pilot pattern of the Preamble symbols shall be signaled by the bootstrap as detailed in Section 9.1.

The number of Preamble symbols in the Preamble $N_P$ shall be indicated by the L1 signaling.

For the first Preamble symbol, the *NoC* used shall be the minimum for the FFT size used for that first Preamble symbol while the *NoC* for the remaining Preamble symbols shall be signaled in L1-Basic.

The frequency interleaver shall always be applied to all of the Preamble symbol(s) as described in Section 7.3.

#### 7.2.5.2 Mapping of L1 Signaling Data to Preamble Symbol(s)

L1-Basic and L1-Detail signaling data shall be encoded and modulated as described in Section 6.5.

L1-Basic cells shall be mapped only to the available cells of the first Preamble symbol, as shown in Figure 7.11. L1-Detail cells shall be interleaved and mapped to the remaining available cells of the first Preamble symbol directly after the L1-Basic cells and to the available cells of the other ($N_P$ – 1) Preamble symbols.

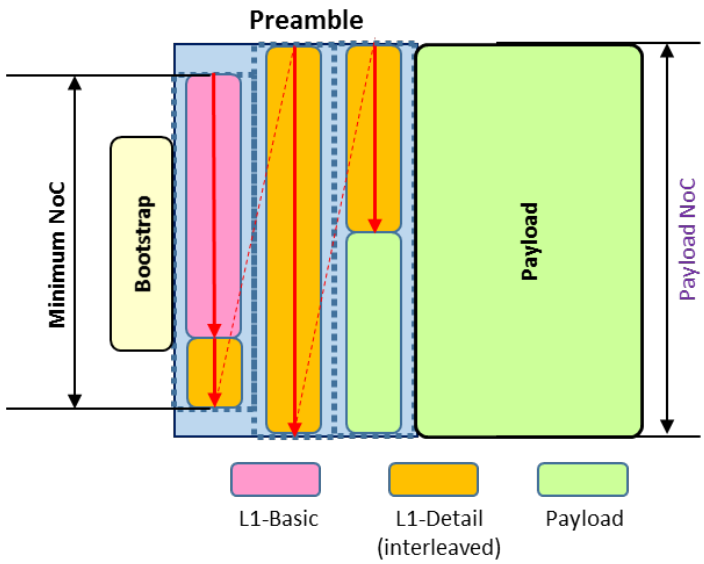


**Figure 7.11** Mapping of L1-Basic and L1-Detail into Preamble symbol(s).

Modulated L1-Detail cells are interleaved and mapped to the Preamble symbols(s) as follows.

The **L1B_L1_Detail_total_cells** cells of L1-Detail shall be interleaved across all the $N_P$ Preamble symbols. Within the first Preamble symbol, L1-Detail shall occupy the data cells that are not occupied by L1-Basic. The L1-Detail interleaver is a Block Interleaver comprised of $L_c = N_P$ columns and $L_r = \lfloor \mathbf{L1B_L1_Detail_total_cells}/N_P \rfloor$ rows.

The first $L_c \times L_r$ L1-Detail cells shall be written sequentially into the Block Interleaver row-wise and read out column by column. The relationship between the L1-Detail cells which form the interleaver input *x(m)* and its output *y(n)*, *m*,*n* = 0,1,.. **L1B_L1_Detail_total_cells** -1 is described by the following equation:

$$y(n) = \begin{cases} x(j \times L_c + i) & \text{where } n = (i \times L_r + j) \text{ and } 0 \le n < L_r \times L_c \\ x(n) & L_r \times L_c \le n < \mathbf{L1B_L1_Detail_total_cells} \end{cases}$$

for $j$ = 0,1, .. $L_r$-1 and $i$ = 0,1, .. $L_c$-1.

The output cells of the interleaver *y(n)* shall be mapped sequentially to the unoccupied data cells of the Preamble symbols, beginning with the first unoccupied data cell of the first Preamble symbol and filling each Preamble symbol before moving on to the next Preamble symbol until all the **L1B_L1_Detail_total_cells** are so mapped.

The available cells that are not used for L1-Detail cells in the last Preamble symbol shall be treated as available data cells when performing cell multiplexing as specified in Section 7.2.6.

#### 7.2.5.3 Generating Preamble waveform

After frequency interleaving, the Preamble pilots shall be inserted in each Preamble symbol as described in Section 8.1.6. Then the Preamble symbol shall pass through an IFFT as described in Section 8.3, followed by addition of a guard interval as detailed in Section 8.5.

MISO or MIMO shall not be applied to any Preamble symbol(s).

LDM shall not be applied to any cells in the Preamble carrying L1-Basic or L1-Detail data but may be applied to payload data cells in the last Preamble symbol.

The FFT size and the duration of the guard interval shall be the same for each Preamble symbol and shall be as indicated by the **preamble_structure** parameter of the bootstrap as shown in Table H.1.1.

### 7.2.6 Cell Multiplexing

The frame builder maps cells from the time interleaver output to the data cells of each subframe as described in the following subsections.

#### 7.2.6.1 Data Cell Indexing

Data cells within a subframe shall be indexed in a one-dimensional fashion beginning at 0 for the first data cell and incrementing the index by 1 for each subsequent data cell. Data cell indexing shall begin with the first frame symbol associated with a subframe for the purposes of data cell multiplexing, which shall be one of the following: the final symbol of a Preamble (only possible for the first subframe of a frame), a subframe boundary symbol, or a data symbol. All of the data cells within a frame symbol shall be indexed before moving on to the following frame symbol of the same subframe. Within a frame symbol, data cell indexing shall begin with the data cell that maps to the lowest index carrier and shall proceed to the data cell that maps to the next lowest index carrier, and so on until all data cells within the frame symbol have been indexed.

Data cells shall be the cells of the OFDM symbols that are not used for pilots nor used for PAPR reduction via tone reservation (TR) (see Section 8.4.1) nor used as null cells.

Figure 7.12 shows an example of data cell indexing for a subframe that begins with the final symbol of a Preamble, concludes with a subframe boundary symbol, and contains data symbols between these two boundaries. In this example, multiple Preamble symbols may be contained within the frame's Preamble, but only the final Preamble symbol is actually able to carry PLP data and has therefore been included in this example.

Similarly, Figure 7.13 shows an example data cell indexing for a subframe that begins with a subframe boundary symbol, concludes with a subframe boundary symbol, and contains data symbols between these two boundaries. No Preamble symbol is associated with this latter example subframe.

Within Figure 7.12 and Figure 7.13, the following quantities are defined:

- $N_C^P$ is the number of available data cells in the final symbol of a Preamble.
- $N_C^D$ is the number of available data cells in a data symbol.
- $N_C^B$ is the number of available data cells in a subframe boundary symbol.

- $N_S^D$ is the number of data symbols present in a subframe.

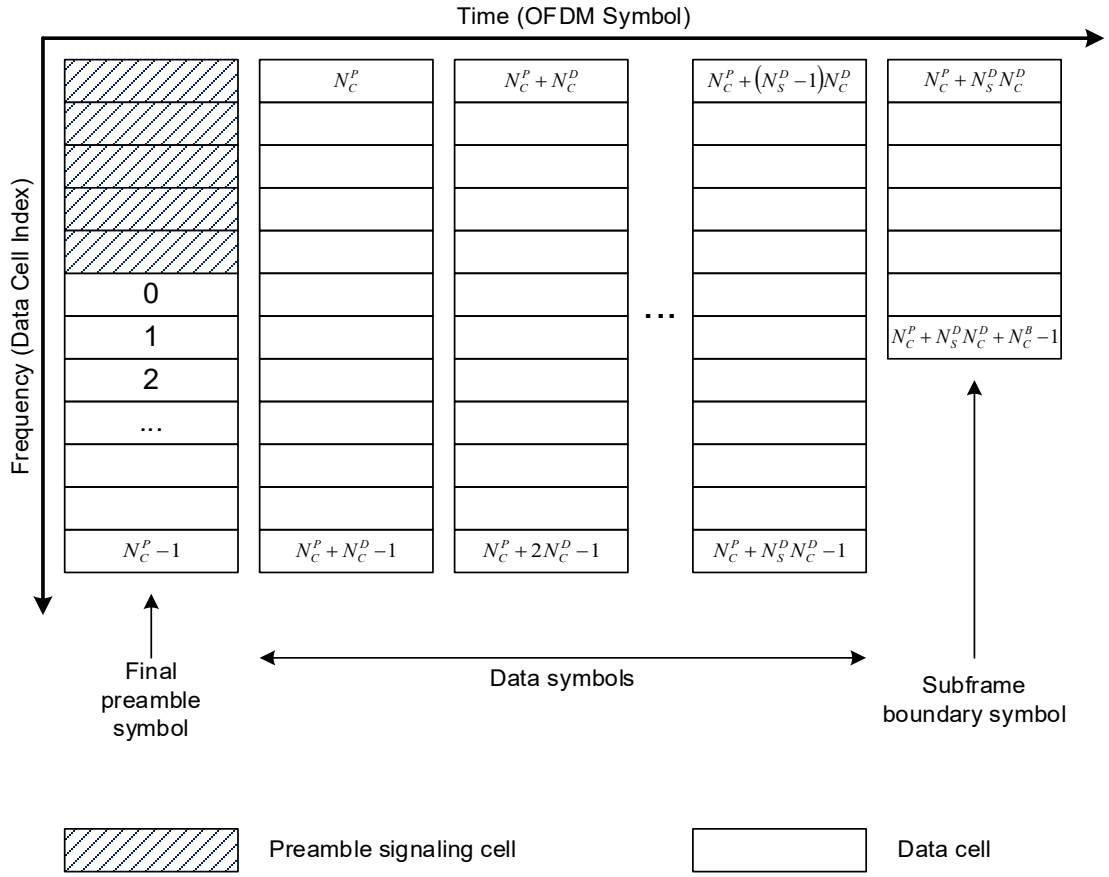


**Figure 7.12** Data cell addressing when a Preamble symbol is associated with a subframe.

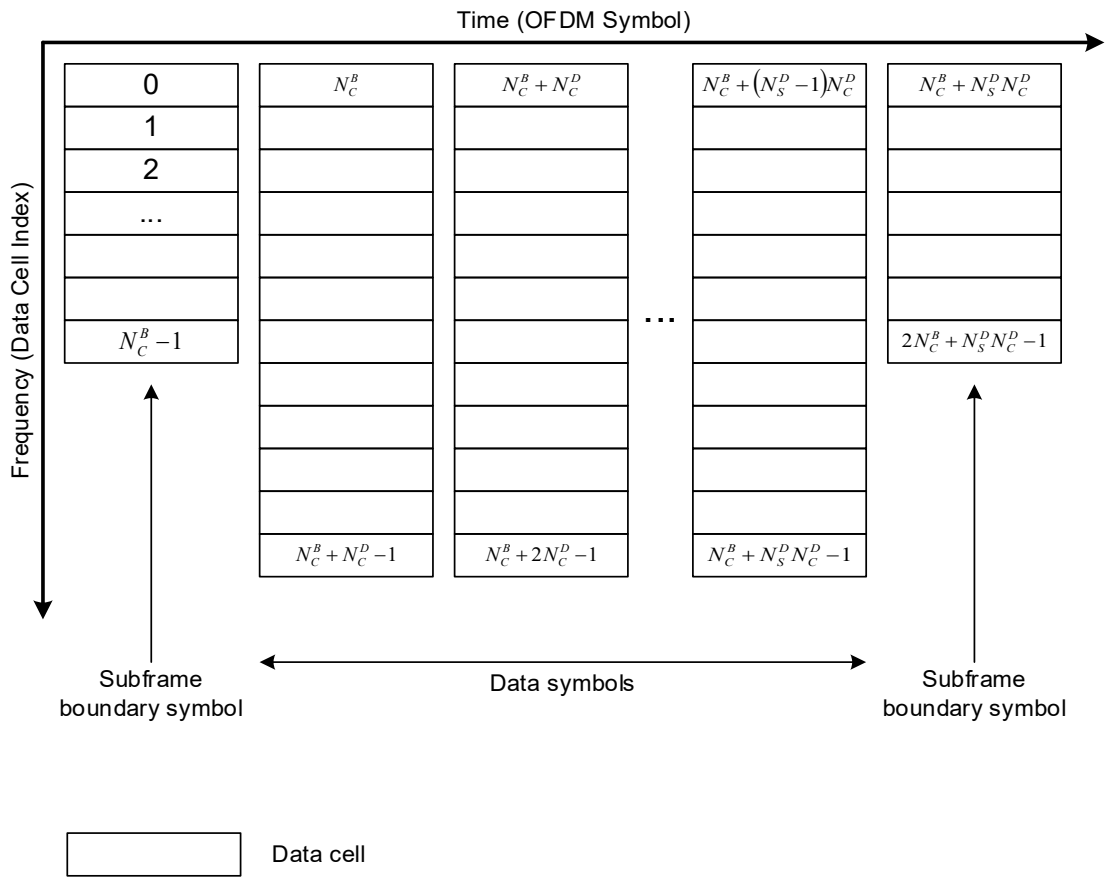


**Figure 7.13** Data cell addressing when a Preamble symbol is not associated with a subframe.

#### 7.2.6.2 Number of Available Data Cells for Preamble Symbols

The number of available data cells per Preamble symbol ($N_C^P$) is a function of the following quantities.

- The Number of Carriers (*NoC*) is as described in Section 7.2.3.
- The number of Preamble pilots, which is a function of the Preamble pilot pattern ($D_X$) and the *NoC*.
- The number of continual pilots per Preamble symbol, which is a function of the Preamble FFT size and the *NoC*.
- Whether or not tone reservation is configured for peak-to-average power ratio (PAPR) reduction. The number of carriers used for TR (if configured) is a function of the FFT size as shown in Table G.1.2.

Note that the data cells in Preamble symbols are primarily used for carrying encoded and modulated L1-Basic and L1-Detail signaling. Data cells in the final Preamble symbol that do not carry L1-Basic or L1-Detail signaling can be used for carrying PLP data cells (see Sections 7.2.5.2 and 7.2.6.1).

The number of available data cells per Preamble symbol shall be as listed in Table 7.2 when tone reservation is not enabled.

When tone reservation is enabled, the number of available data cells per data symbol shall be equal to the corresponding quantities from Table 7.2 minus the number of reserved carriers for the associated FFT size as shown in Table G.1.2.

**Table 7.2** Number of Available Data Cells per Preamble Symbol

| FFT Size | GI Length (samples) | Pilot Pattern ($D_x$) | $C_{red_coeff}$ | | | | |
|---|---|---|---|---|---|---|---|
| | | | 0 | 1 | 2 | 3 | 4 |
| 8K | 192 | 16 | 6432 | 6342 | 6253 | 6164 | 6075 |
| 8K | 384 | 8 | 6000 | 5916 | 5833 | 5750 | 5667 |
| 8K | 512 | 6 | 5712 | 5632 | 5553 | 5474 | 5395 |
| 8K | 768 | 4 | 5136 | 5064 | 4993 | 4922 | 4851 |
| 8K | 1024 | 3 | 4560 | 4496 | 4433 | 4370 | 4307 |
| 8K | 1536 | 4 | 5136 | 5064 | 4993 | 4922 | 4851 |
| 8K | 2048 | 3 | 4560 | 4496 | 4433 | 4370 | 4307 |
| 16K | 192 | 32 | 13296 | 13110 | 12927 | 12742 | 12558 |
| 16K | 384 | 16 | 12864 | 12684 | 12507 | 12328 | 12150 |
| 16K | 512 | 12 | 12576 | 12400 | 12227 | 12052 | 11878 |
| 16K | 768 | 8 | 12000 | 11832 | 11667 | 11500 | 11334 |
| 16K | 1024 | 6 | 11424 | 11264 | 11107 | 10948 | 10790 |
| 16K | 1536 | 4 | 10272 | 10128 | 9987 | 9844 | 9702 |
| 16K | 2048 | 3 | 9120 | 8992 | 8867 | 8740 | 8614 |
| 16K | 2432 | 3 | 9120 | 8992 | 8867 | 8740 | 8614 |
| 16K | 3072 | 4 | 10272 | 10128 | 9987 | 9844 | 9702 |
| 16K | 3648 | 4 | 10272 | 10128 | 9987 | 9844 | 9702 |
| 16K | 4096 | 3 | 9120 | 8992 | 8867 | 8740 | 8614 |
| 32K | 192 | 32 | 26592 | 26220 | 25854 | 25484 | 25116 |
| 32K | 384 | 32 | 26592 | 26220 | 25854 | 25484 | 25116 |
| 32K | 512 | 24 | 26304 | 25936 | 25574 | 25208 | 24844 |
| 32K | 768 | 16 | 25728 | 25368 | 25014 | 24656 | 24300 |
| 32K | 1024 | 12 | 25152 | 24800 | 24454 | 24104 | 23756 |
| 32K | 1536 | 8 | 24000 | 23664 | 23334 | 23000 | 22668 |
| 32K | 2048 | 6 | 22848 | 22528 | 22214 | 21896 | 21580 |
| 32K | 2432 | 6 | 22848 | 22528 | 22214 | 21896 | 21580 |
| 32K | 3072 | 8 | 24000 | 23664 | 23334 | 23000 | 22668 |
| 32K | 3072 | 3 | 18240 | 17984 | 17734 | 17480 | 17228 |
| 32K | 3648 | 8 | 24000 | 23664 | 23334 | 23000 | 22668 |
| 32K | 3648 | 3 | 18240 | 17984 | 17734 | 17480 | 17228 |
| 32K | 4096 | 3 | 18240 | 17984 | 17734 | 17480 | 17228 |
| 32K | 4864 | 3 | 18240 | 17984 | 17734 | 17480 | 17228 |

#### 7.2.6.3 Number of Available Data Cells for Data Symbols

The number of available data cells per data symbol ($N_C^D$) is a function of the following quantities.

- The Number of Carriers (*NoC*) is as described in Section 7.2.3.
- The number of scattered pilots per OFDM symbol, which is a function of the scattered pilot pattern and the *NoC*.
- The number of continual pilots per OFDM symbol, which is a function of the FFT size and the *NoC*.

- Whether or not tone reservation is configured for peak-to-average power ratio (PAPR) reduction. The number of carriers used for TR (if configured) is a function of the FFT size as shown in Table G.1.2.

The number of available data cells per data symbol shall be as listed in Table 7.3 and Table 7.4 when tone reservation is not enabled. Table entries shown in brackets and italicized are for FFT size and scattered pilot pattern combinations that are not allowed (refer to Table 8.3).

When tone reservation is enabled, the number of available data cells per data symbol shall be equal to the corresponding quantities from Table 7.3 and Table 7.4 minus the number of reserved carriers for the associated FFT size as shown in Table G.1.2.

**Table 7.3** Number of Available Data Cells per Data Symbol

| **FFT Size** | ***$C_{red_coeff}$*** | ***NoC*** | **Available data cells per data symbol** | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | **SP3_2** | **SP3_4** | **SP4_2** | **SP4_4** | **SP6_2** | **SP6_4** | **SP8_2** | **SP8_4** |
| **8K** | 0 | 6913 | 5711 | 6285 | 5999 | 6429 | 6287 | 6573 | 6431 | 6645 |
| | 1 | 6817 | 5631 | 6197 | 5915 | 6339 | 6199 | 6481 | 6341 | 6552 |
| | 2 | 6721 | 5552 | 6110 | 5832 | 6250 | 6112 | 6390 | 6252 | 6460 |
| | 3 | 6625 | 5473 | 6023 | 5749 | 6161 | 6025 | 6299 | 6163 | 6368 |
| | 4 | 6529 | 5394 | 5936 | 5666 | 6072 | 5938 | 6208 | 6074 | 6276 |
| **16K** | 0 | 13825 | 11423 | 12573 | 11999 | 12861 | 12575 | 13149 | 12863 | 13293 |
| | 1 | 13633 | 11263 | 12397 | 11831 | 12681 | 12399 | 12965 | 12683 | 13107 |
| | 2 | 13441 | 11106 | 12224 | 11666 | 12504 | 12226 | 12784 | 12506 | 12924 |
| | 3 | 13249 | 10947 | 12049 | 11499 | 12325 | 12051 | 12601 | 12327 | 12739 |
| | 4 | 13057 | 10789 | 11875 | 11333 | 12147 | 11877 | 12419 | 12149 | 12555 |
| **32K** | 0 | 27649 | 22847 | *(25149)* | *N/A* | *N/A* | 25151 | *(26301)* | 25727 | *(26589)* |
| | 1 | 27265 | 22527 | *(24797)* | *N/A* | *N/A* | 24799 | *(25933)* | 25367 | *(26217)* |
| | 2 | 26881 | 22213 | *(24451)* | *N/A* | *N/A* | 24453 | *(25571)* | 25013 | *(25851)* |
| | 3 | 26497 | 21895 | *(24101)* | *N/A* | *N/A* | 24103 | *(25205)* | 24655 | *(25481)* |
| | 4 | 26113 | 21579 | *(23753)* | *N/A* | *N/A* | 23755 | *(24841)* | 24299 | *(25113)* |

**Table 7.4** Number of Available Data Cells per Data Symbol

| FFT Size | $C_{red_coeff}$ | *NoC* | Available data cells per data symbol | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | **SP12_2** | **SP12_4** | **SP16_2** | **SP16_4** | **SP24_2** | **SP24_4** | **SP32_2** | **SP32_4** |
| **8K** | 0 | 6913 | 6575 | 6717 | 6647 | 6753 | *(6719)* | *(6789)* | 6755 | 6807 |
| | 1 | 6817 | 6483 | 6623 | 6554 | 6660 | *(6625)* | *(6694)* | 6661 | 6714 |
| | 2 | 6721 | 6392 | 6530 | 6462 | 6565 | *(6532)* | *(6600)* | 6567 | 6619 |
| | 3 | 6625 | 6301 | 6437 | 6370 | 6473 | *(6439)* | *(6506)* | 6474 | 6524 |
| | 4 | 6529 | 6210 | 6344 | 6278 | 6378 | *(6346)* | *(6412)* | 6380 | 6429 |
| **16K** | 0 | 13825 | 13151 | 13437 | 13295 | 13509 | 13439 | 13581 | 13511 | 13617 |
| | 1 | 13633 | 12967 | 13249 | 13109 | 13320 | 13251 | 13391 | 13322 | 13428 |
| | 2 | 13441 | 12786 | 13064 | 12926 | 13134 | 13066 | 13204 | 13136 | 13239 |
| | 3 | 13249 | 12603 | 12877 | 12741 | 12946 | 12879 | 13015 | 12948 | 13051 |
| | 4 | 13057 | 12421 | 12691 | 12557 | 12759 | 12693 | 12827 | 12761 | 12861 |
| **32K** | 0 | 27649 | 26303 | *(26877)* | 26591 | *(27021)* | 26879 | *(27165)* | 27023 | *(27237)* |
| | 1 | 27265 | 25935 | *(26501)* | 26219 | *(26643)* | 26503 | *(26785)* | 26645 | *(26856)* |
| | 2 | 26881 | 25573 | *(26131)* | 25853 | *(26271)* | 26133 | *(26411)* | 26273 | *(26481)* |
| | 3 | 26497 | 25207 | *(25757)* | 25483 | *(25895)* | 25759 | *(26033)* | 25897 | *(26102)* |
| | 4 | 26113 | 24843 | *(25385)* | 25115 | *(25521)* | 25387 | *(25657)* | 25523 | *(25725)* |

#### 7.2.6.4 Number and Position of Available Data Cells for Subframe Boundary Symbols

The following terms are defined:

- $N_{Data}^{B}$ is the total number of data cells (non-pilot cells) including both null and active data cells in a subframe boundary symbol.
- $NoA_{SBS}$ is the number of active data cells in a subframe boundary symbol. The number of available data cells per subframe boundary symbol for cell multiplexing purposes is $N_{C}^{B} = NoA_{SBS}$.
- $N_{Null}^{B}$ is the number of null cells in a subframe boundary symbol. $N_{Null}^{B} = N_{Data}^{B} - NoA_{SBS}$

The total number of data cells in a subframe boundary symbol ($N_{Data}^{B}$) shall be as listed in Table 7.5 and Table 7.6 when tone reservation is not enabled. Table entries shown in brackets and italicized are for FFT size and scattered pilot pattern combinations that are not allowed (refer to Table 8.3).

When tone reservation is enabled, the total number of data cells in a subframe boundary symbol shall be equal to the corresponding quantities from Table 7.5 and Table 7.6 minus the number of reserved carriers for the associated FFT size as shown in Table G.1.2 and Table G.1.3, that is, 72 for 8K FFT, 144 for 16K FFT and 288 for 32K FFT size respectively.

**Table 7.5** Total Number of Data Cells in a Subframe Boundary Symbol

| FFT Size | $C_{red_coeff}$ | *NoC* | Total data cells in a subframe boundary symbol | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | **SP3_2** | **SP3_4** | **SP4_2** | **SP4_4** | **SP6_2** | **SP6_4** | **SP8_2** | **SP8_4** |
| **8K** | 0 | 6913 | 4560 | 4560 | 5136 | 5136 | 5712 | 5712 | 6000 | 6000 |
| | 1 | 6817 | 4496 | 4496 | 5064 | 5064 | 5632 | 5632 | 5916 | 5916 |
| | 2 | 6721 | 4433 | 4433 | 4993 | 4993 | 5553 | 5553 | 5833 | 5833 |
| | 3 | 6625 | 4370 | 4370 | 4922 | 4922 | 5474 | 5474 | 5750 | 5750 |
| | 4 | 6529 | 4307 | 4307 | 4851 | 4851 | 5395 | 5395 | 5667 | 5667 |
| **16K** | 0 | 13825 | 9120 | 9120 | 10272 | 10272 | 11424 | 11424 | 12000 | 12000 |
| | 1 | 13633 | 8992 | 8992 | 10128 | 10128 | 11264 | 11264 | 11832 | 11832 |
| | 2 | 13441 | 8867 | 8867 | 9987 | 9987 | 11107 | 11107 | 11667 | 11667 |
| | 3 | 13249 | 8740 | 8740 | 9844 | 9844 | 10948 | 10948 | 11500 | 11500 |
| | 4 | 13057 | 8614 | 8614 | 9702 | 9702 | 10790 | 10790 | 11334 | 11334 |
| **32K** | 0 | 27649 | 18240 | *(18240)* | *N/A* | *N/A* | 22848 | *(22848)* | 24000 | *(24000)* |
| | 1 | 27265 | 17984 | *(17984)* | *N/A* | *N/A* | 22528 | *(22528)* | 23664 | *(23664)* |
| | 2 | 26881 | 17734 | *(17734)* | *N/A* | *N/A* | 22214 | *(22214)* | 23334 | *(23334)* |
| | 3 | 26497 | 17480 | *(17480)* | *N/A* | *N/A* | 21896 | *(21896)* | 23000 | *(23000)* |
| | 4 | 26113 | 17228 | *(17228)* | *N/A* | *N/A* | 21580 | *(21580)* | 22668 | *(22668)* |

**Table 7.6** Total Number of Data Cells in a Subframe Boundary Symbol

| FFT Size | $C_{red_coeff}$ | *NoC* | Total data cells in a subframe boundary symbol | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | **SP12_2** | **SP12_4** | **SP16_2** | **SP16_4** | **SP24_2** | **SP24_4** | **SP32_2** | **SP32_4** |
| **8K** | 0 | 6913 | 6288 | 6288 | 6432 | 6432 | *(6576)* | *(6576)* | 6648 | 6648 |
| | 1 | 6817 | 6200 | 6200 | 6342 | 6342 | *(6484)* | *(6484)* | 6555 | 6555 |
| | 2 | 6721 | 6113 | 6113 | 6253 | 6253 | *(6393)* | *(6393)* | 6463 | 6463 |
| | 3 | 6625 | 6026 | 6026 | 6164 | 6164 | *(6302)* | *(6302)* | 6371 | 6371 |
| | 4 | 6529 | 5939 | 5939 | 6075 | 6075 | *(6211)* | *(6211)* | 6279 | 6279 |
| **16K** | 0 | 13825 | 12576 | 12576 | 12864 | 12864 | 13152 | 13152 | 13296 | 13296 |
| | 1 | 13633 | 12400 | 12400 | 12684 | 12684 | 12968 | 12968 | 13110 | 13110 |
| | 2 | 13441 | 12227 | 12227 | 12507 | 12507 | 12787 | 12787 | 12927 | 12927 |
| | 3 | 13249 | 12052 | 12052 | 12328 | 12328 | 12604 | 12604 | 12742 | 12742 |
| | 4 | 13057 | 11878 | 11878 | 12150 | 12150 | 12422 | 12422 | 12558 | 12558 |
| **32K** | 0 | 27649 | 25152 | *(25152)* | 25728 | *(25728)* | 26304 | *(26304)* | 26592 | *(26592)* |
| | 1 | 27265 | 24800 | *(24800)* | 25368 | *(25368)* | 25936 | *(25936)* | 26220 | *(26220)* |
| | 2 | 26881 | 24454 | *(24454)* | 25014 | *(25014)* | 25574 | *(25574)* | 25854 | *(25854)* |
| | 3 | 26497 | 24104 | *(24104)* | 24656 | *(24656)* | 25208 | *(25208)* | 25484 | *(25484)* |
| | 4 | 26113 | 23756 | *(23756)* | 24300 | *(24300)* | 24844 | *(24844)* | 25116 | *(25116)* |

The number of active data cells in a subframe boundary symbol ($NoA_{SBS}$) is dependent on the amplitude of the scattered pilots signaled with **L1D_scattered_pilot_boost**.

The number of active data cells in a subframe boundary symbol for each **L1_scattered_pilot_boost** value shall be as listed in Table F.1.1 to Table F.1.10. Table entries shown in brackets and italicized are for FFT size and scattered pilot pattern combinations that are not allowed (refer to Table 8.3).

When tone reservation is enabled, the number of active data cells in a subframe boundary symbol shall be equal to the corresponding quantities from Table F.1.1 to Table F.1.10 minus the

number of reserved carriers for the associated FFT size as shown in Table G.1.2 and Table G.1.3, that is, 72 for 8K FFT, 144 for 16K FFT and 288 for 32K FFT size respectively.

The number of null cells in a subframe boundary symbol ($N_{Null}^{B}$) is also dependent on the amplitude of the scattered pilots of the subframe (determined from the value signaled by **L1D_scattered_pilot_boost**). The number of null cells in a subframe boundary symbol can be obtained by subtracting the number of active data cells in a subframe boundary symbol from the total number of data cells (Table 7.5 and Table 7.6). The number of null cells in a subframe boundary symbol shall be signaled by **L1D_sbs_null_cells.**

The active data cells shall be centered within the total data cells, with half of the null cells being positioned at each band edge as shown in Figure 7.14.

- Null cells shall occupy the $\lfloor N_{Null}^{B}/2 \rfloor$ lowest-frequency data carriers and the $\lceil N_{Null}^{B}/2 \rceil$ highest-frequency data carriers.
- The data carriers between these two sets of null carriers shall be active data carriers and shall be indexed as described in Section 7.2.6.1 for the purposes of data cell multiplexing.

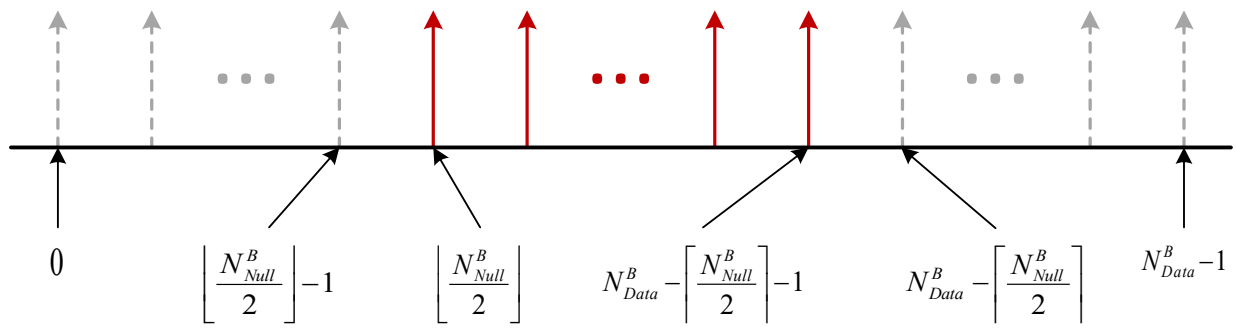


**Figure 7.14** Data carrier indices for null and active data carriers.

#### 7.2.6.5 Insertion of Dummy Modulation Values

Depending upon the exact subframe configuration and PLP multiplexing parameters, the available data cells of a subframe may be fully or partially occupied by PLP data. In the event that not all of the available data cells have PLP data mapped to them, it is important that these unoccupied data cells are modulated rather than remaining as unmodulated null cells in order to ensure a constant transmit power. This is accomplished by assigning pseudo-random dummy modulation values to the unoccupied data cells.

Unoccupied data cells could conceivably occur anywhere within a subframe, depending upon the exact PLP multiplexing parameters. Therefore, all of the available data cells of a subframe shall first be filled with dummy modulation values, and then the cell multiplexing process shall overwrite the dummy modulation values of occupied data cells with actual PLP data. This approach ensures that every available data cell in a subframe is modulated either by a PLP cell or by a dummy modulation value.

Let $N_{cell}$ be the total number of available data cells in a subframe with those data cells being indexed from 0 to $N_{cell} - 1$ as described in Section 7.2.6.1.

Let $d_i$ be the dummy modulation value for the data cell with index $i$ ($0 \leq i < N_{cell}$).

Let $b_i$ ($0 \leq i < N_{cell}$) represent the $i$th value of the Baseband Packet scrambling sequence described in Section 5.2.3.

Then the dummy modulation value for the $i$th data cell ($0 \leq i < N_{cell}$) shall be calculated as given in the following pair of equations.

$$\mathrm{Re}\{d_i\} = 1 - 2 \times b_i$$

$$\mathrm{Im}\{d_i\} = 0$$

Each of the $N_{cell}$ available data cells in the subframe shall have its corresponding dummy modulation value assigned to it prior to any PLP data being multiplexed into the subframe. Following the insertion of these dummy modulation values, PLP data belonging to the current subframe shall be mapped to the corresponding data cells allocated for that PLP data and shall overwrite the dummy modulation values previously assigned to those data cells.

Note that the available data cells in the first subframe of a frame might begin in the final Preamble symbol of that frame as specified in Section 7.2.5.2.

#### 7.2.6.6 PLP Types

Each PLP that is not an LDM Enhanced PLP shall be one of the following two PLP types: a non-dispersed PLP or a dispersed PLP.

The data cells of a non-dispersed PLP shall be allocated to contiguous data cell indices of the subframe. That is, all of the data cell indices between the lowest data cell index allocated to a non-dispersed PLP and the highest data cell index allocated to the same non-dispersed PLP, inclusive, shall also be allocated to the same non-dispersed PLP.

A dispersed PLP shall consist of two or more subslices. The data cells within a single subslice of a dispersed PLP shall be allocated to contiguous data cell indices of the subframe. However, two consecutive subslices of the same dispersed PLP shall not have contiguous data cell indices with each other. That is, the difference between the lowest data cell index allocated to a subslice of a dispersed PLP and the highest data cell index allocated to the immediately preceding subslice of the same dispersed PLP shall be greater than one.

The type of a particular PLP **L1D_plp_type** shall be signaled independently for each subframe in which that PLP appears. A PLP shall not be constrained to be of the same type for two different subframes in which that PLP appears.

When LDM is used, **L1D_plp_type** shall be signaled only for Core PLPs. Enhanced PLPs shall not have a specific PLP type associated with them.

#### 7.2.6.7 PLP Positioning

The starting position of a PLP **L1D_plp_start** may lie anywhere within a subframe regardless of the type of the PLP. The starting position of a PLP shall be the index of the data cell assigned to hold the first data cell value of the PLP.

The length of a PLP **L1D_plp_size** shall indicate the total number of data cells contained by the PLP for the current subframe.

The starting position and length of a PLP in a subframe shall be independent of and shall be signaled independently of the starting position and length of the same PLP in all other subframes. The starting position and length of every PLP present in a subframe shall be signaled, regardless of whether or not LDM is used.

A PLP's cell allocation parameters (i.e. the starting position, length, and subslicing parameters (the subslicing parameters shall only be included for a dispersed PLP)) shall be configured so that

all data cells allocated to that PLP lie within the range of valid data cell indices for the current subframe.

Each data cell within a subframe shall be allocated to a maximum of one PLP per LDM layer.

Let $S_{PLP}$ be the size and $P_{start}$ be the starting position of a non-dispersed PLP within a subframe. The non-dispersed PLP's input data cells 0 through $S_{PLP} - 1$, inclusive, shall be mapped respectively to data cell indices $P_{start}$ through $P_{start} + S_{PLP} - 1$, inclusive, within the subframe.

#### 7.2.6.8 Subslicing

A dispersed PLP shall be divided into two or more subslices. Each subslice shall occupy a set of contiguous data cell indices, but the highest data cell index of a subslice shall be non-contiguous to the lowest data cell index of the following subslice of the same PLP.

Every subslice, with the possible exception of the final subslice, of a particular dispersed PLP within a subframe shall have the same non-zero size. The size of the final subslice of a dispersed PLP within a subframe shall be greater than zero and less than or equal to the size of the other subslices of the same PLP within the same subframe. The subslice interval (**L1D_plp_subslice_interval**) between the lowest data cell index of a subslice of a dispersed PLP and the lowest data cell index of the following subslice of the same PLP shall be the same for all subslices of that PLP within a subframe.

The number of subslices, subslice size, and subslice interval for a dispersed PLP shall be independent of and shall be signaled independently of the number of subslices, subslice size and subslice interval of all other dispersed PLPs within the same subframe.

The number of subslices, subslice size, and subslice interval for a dispersed PLP in a subframe shall be independent of and shall be signaled independently of the number of subslices, subslice size, and subslice interval of the same PLP in all other subframes.

When LDM is used, the number of subslices and subslice interval shall be signaled only for dispersed Core PLPs.

Let $S_{PLP}$ be the size, $P_{start}$ be the starting position, $N_{subslices}$ be the number of subslices, and $I_{subslice}$ be the subslice interval of a dispersed PLP within a subframe. The subslice size of the dispersed PLP can be calculated as $S_{subslice} = \lceil S_{PLP}/N_{subslices} \rceil$. Data cell $k$ of the dispersed PLP's input data ($0 \leq k < S_{PLP}$) shall be mapped to data cell index $P_{start} + \lfloor k/S_{subslice} \rfloor \times I_{subslice} + k \bmod S_{subslice}$ within the subframe.

A non-dispersed PLP shall not be subsliced and shall not have any subslicing parameters associated with it.

### 7.2.7 PLP Multiplexing Approaches within a Subframe

This section contains an overview on how the cell multiplexing method described in Section 7.2.6 can be used to enable specific styles of PLP multiplexing, complete with an illustrative example of each multiplexing approach. The examples included here use the example data cell indices shown in Figure 7.15. Layered Division Multiplexing of PLPs is considered in detail in Section 7.2.7.4.

Time →

Frequency ↓

| | | | | | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 000 | 010 | 020 | 030 | 040 | 050 | 060 | 070 | 080 | 090 | 100 | 110 | 120 | 130 | 140 | 150 | 160 | 170 | 180 | 190 | 200 | 210 | 220 | 230 | 240 | 250 |
| 001 | 011 | 021 | 031 | 041 | 051 | 061 | 071 | 081 | 091 | 101 | 111 | 121 | 131 | 141 | 151 | 161 | 171 | 181 | 191 | 201 | 211 | 221 | 231 | 241 | 251 |
| 002 | 012 | 022 | 032 | 042 | 052 | 062 | 072 | 082 | 092 | 102 | 112 | 122 | 132 | 142 | 152 | 162 | 172 | 182 | 192 | 202 | 212 | 222 | 232 | 242 | 252 |
| 003 | 013 | 023 | 033 | 043 | 053 | 063 | 073 | 083 | 093 | 103 | 113 | 123 | 133 | 143 | 153 | 163 | 173 | 183 | 193 | 203 | 213 | 223 | 233 | 243 | 253 |
| 004 | 014 | 024 | 034 | 044 | 054 | 064 | 074 | 084 | 094 | 104 | 114 | 124 | 134 | 144 | 154 | 164 | 174 | 184 | 194 | 204 | 214 | 224 | 234 | 244 | 254 |
| 005 | 015 | 025 | 035 | 045 | 055 | 065 | 075 | 085 | 095 | 105 | 115 | 125 | 135 | 145 | 155 | 165 | 175 | 185 | 195 | 205 | 215 | 225 | 235 | 245 | 255 |
| 006 | 016 | 026 | 036 | 046 | 056 | 066 | 076 | 086 | 096 | 106 | 116 | 126 | 136 | 146 | 156 | 166 | 176 | 186 | 196 | 206 | 216 | 226 | 236 | 246 | 256 |
| 007 | 017 | 027 | 037 | 047 | 057 | 067 | 077 | 087 | 097 | 107 | 117 | 127 | 137 | 147 | 157 | 167 | 177 | 187 | 197 | 207 | 217 | 227 | 237 | 247 | 257 |
| 008 | 018 | 028 | 038 | 048 | 058 | 068 | 078 | 088 | 098 | 108 | 118 | 128 | 138 | 148 | 158 | 168 | 178 | 188 | 198 | 208 | 218 | 228 | 238 | 248 | 258 |
| 009 | 019 | 029 | 039 | 049 | 059 | 069 | 079 | 089 | 099 | 109 | 119 | 129 | 139 | 149 | 159 | 169 | 179 | 189 | 199 | 209 | 219 | 229 | 239 | 249 | 259 |

**Figure 7.15** Data cell indices used for illustrative multiplexing examples.

### 7.2.7.1 Overview

#### 7.2.7.1.1 Simple Multiplexing of PLPs

The simplest multiplexing strategy is when there is only one Core PLP, and the output of the time interleaver is mapped to data cells which are ordered in data symbols within the subframe. This is described in Section 7.2.7.2. For all other cases apart from this single PLP per subframe case, there are various ways to multiplex the multiple PLPs onto the frame. The following sections describe the multiplexing techniques used in this specification. The specific multiplexing techniques defined are:

- Time division multiplexing (TDM) , described in Section 7.2.7.3
- Layered division multiplexing (LDM), described in Section 7.2.7.4
- Frequency division multiplexing (FDM) , described in Section 7.2.7.5

#### 7.2.7.1.2 Complex Multiplexing of PLPs

LDM can be combined in many ways, some of them quite complex. Complex LDM examples are described in Sections 7.2.7.4.2 to 7.2.7.4.5. Furthermore, there are various combinations of the multiplexing techniques that can be used. Time and frequency division multiplexing (TFDM) is described in Section 7.2.7.6.

### 7.2.7.2 Single Physical Layer Pipe

The simplest structure for a physical layer frame is when there is only one PLP per subframe.

Table 7.7 and Figure 7.16 show an example of the cell multiplexing parameters and the resulting graphical view of the cell multiplexing.

**Table 7.7** Example Parameters for the Cell Multiplexing of a Single PLP

| L1D_plp_ id | L1D_plp _ size | L1D_plp_ type | L1D_plp _ start | L1D_plp_ num_subslices | L1D_plp_ subslice_interval |
|---|---|---|---|---|---|
| A | 260 | 0 (Non-dispersed) | 000 | *N/A* | *N/A* |

Time →

Frequency ↓

| | | | | | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| A000 | A010 | A020 | A030 | A040 | A050 | A060 | A070 | A080 | A090 | A100 | A110 | A120 | A130 | A140 | A150 | A160 | A170 | A180 | A190 | A200 | A210 | A220 | A230 | A240 | A250 |
| A001 | A011 | A021 | A031 | A041 | A051 | A061 | A071 | A081 | A091 | A101 | A111 | A121 | A131 | A141 | A151 | A161 | A171 | A181 | A191 | A201 | A211 | A221 | A231 | A241 | A251 |
| A002 | A012 | A022 | A032 | A042 | A052 | A062 | A072 | A082 | A092 | A102 | A112 | A122 | A132 | A142 | A152 | A162 | A172 | A182 | A192 | A202 | A212 | A222 | A232 | A242 | A252 |
| A003 | A013 | A023 | A033 | A043 | A053 | A063 | A073 | A083 | A093 | A103 | A113 | A123 | A133 | A143 | A153 | A163 | A173 | A183 | A193 | A203 | A213 | A223 | A233 | A243 | A253 |
| A004 | A014 | A024 | A034 | A044 | A054 | A064 | A074 | A084 | A094 | A104 | A114 | A124 | A134 | A144 | A154 | A164 | A174 | A184 | A194 | A204 | A214 | A224 | A234 | A244 | A254 |
| A005 | A015 | A025 | A035 | A045 | A055 | A065 | A075 | A085 | A095 | A105 | A115 | A125 | A135 | A145 | A155 | A165 | A175 | A185 | A195 | A205 | A215 | A225 | A235 | A245 | A255 |
| A006 | A016 | A026 | A036 | A046 | A056 | A066 | A076 | A086 | A096 | A106 | A116 | A126 | A136 | A146 | A156 | A166 | A176 | A186 | A196 | A206 | A216 | A226 | A236 | A246 | A256 |
| A007 | A017 | A027 | A037 | A047 | A057 | A067 | A077 | A087 | A097 | A107 | A117 | A127 | A137 | A147 | A157 | A167 | A177 | A187 | A197 | A207 | A217 | A227 | A237 | A247 | A257 |
| A008 | A018 | A028 | A038 | A048 | A058 | A068 | A078 | A088 | A098 | A108 | A118 | A128 | A138 | A148 | A158 | A168 | A178 | A188 | A198 | A208 | A218 | A228 | A238 | A248 | A258 |
| A009 | A019 | A029 | A039 | A049 | A059 | A069 | A079 | A089 | A099 | A109 | A119 | A129 | A139 | A149 | A159 | A169 | A179 | A189 | A199 | A209 | A219 | A229 | A239 | A249 | A259 |

**Figure 7.16** Example of cell multiplexing for a single PLP per subframe.

#### 7.2.7.3 Time Division Multiplexing (TDM)

The concatenation in time of multiple PLPs within a subframe can be achieved simply by using non-dispersed PLPs instead of dispersed PLPs.

Table 7.8 and Figure 7.17 show the cell multiplexing parameters and the resulting graphical view for an example of the time division multiplexing of six PLPs.

**Table 7.8** Example Parameters for Time Division Multiplexing of PLPs

| L1D_plp_ id | L1D_plp_ size | L1D_plp_type | L1D_plp_ start | L1D_plp_num_ subslices | L1D_plp_ subslice_interval |
|---|---|---|---|---|---|
| A | 12 | Non-dispersed | 000 | *N/A* | *N/A* |
| B | 24 | Non-dispersed | 012 | *N/A* | *N/A* |
| C | 80 | Non-dispersed | 036 | *N/A* | *N/A* |
| D | 52 | Non-dispersed | 116 | *N/A* | *N/A* |
| E | 60 | Non-dispersed | 168 | *N/A* | *N/A* |
| F | 32 | Non-dispersed | 228 | *N/A* | *N/A* |

Time →

Frequency ↓

| | | | | | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| A00 | A10 | B08 | B18 | C04 | C14 | C24 | C34 | C44 | C54 | C64 | C74 | D04 | D14 | D24 | D34 | D44 | E02 | E12 | E22 | E32 | E42 | E52 | F02 | F12 | F22 |
| A01 | A11 | B09 | B19 | C05 | C15 | C25 | C35 | C45 | C55 | C65 | C75 | D05 | D15 | D25 | D35 | D45 | E03 | E13 | E23 | E33 | E43 | E53 | F03 | F13 | F23 |
| A02 | B00 | B10 | B20 | C06 | C16 | C26 | C36 | C46 | C56 | C66 | C76 | D06 | D16 | D26 | D36 | D46 | E04 | E14 | E24 | E34 | E44 | E54 | F04 | F14 | F24 |
| A03 | B01 | B11 | B21 | C07 | C17 | C27 | C37 | C47 | C57 | C67 | C77 | D07 | D17 | D27 | D37 | D47 | E05 | E15 | E25 | E35 | E45 | E55 | F05 | F15 | F25 |
| A04 | B02 | B12 | B22 | C08 | C18 | C28 | C38 | C48 | C58 | C68 | C78 | D08 | D18 | D28 | D38 | D48 | E06 | E16 | E26 | E36 | E46 | E56 | F06 | F16 | F26 |
| A05 | B03 | B13 | B23 | C09 | C19 | C29 | C39 | C49 | C59 | C69 | C79 | D09 | D19 | D29 | D39 | D49 | E07 | E17 | E27 | E37 | E47 | E57 | F07 | F17 | F27 |
| A06 | B04 | B14 | C00 | C10 | C20 | C30 | C40 | C50 | C60 | C70 | D00 | D10 | D20 | D30 | D40 | D50 | E08 | E18 | E28 | E38 | E48 | E58 | F08 | F18 | F28 |
| A07 | B05 | B15 | C01 | C11 | C21 | C31 | C41 | C51 | C61 | C71 | D01 | D11 | D21 | D31 | D41 | D51 | E09 | E19 | E29 | E39 | E49 | E59 | F09 | F19 | F29 |
| A08 | B06 | B16 | C02 | C12 | C22 | C32 | C42 | C52 | C62 | C72 | D02 | D12 | D22 | D32 | D42 | E00 | E10 | E20 | E30 | E40 | E50 | F00 | F10 | F20 | F30 |
| A09 | B07 | B17 | C03 | C13 | C23 | C33 | C43 | C53 | C63 | C73 | D03 | D13 | D23 | D33 | D43 | E01 | E11 | E21 | E31 | E41 | E51 | F01 | F11 | F21 | F31 |

**Figure 7.17** Example of time division multiplexing of PLPs.

#### 7.2.7.4 Layered Division Multiplexing (LDM)

When Layered Division Multiplexing (LDM) is used, each PLP present in a subframe shall be classified as either a Core PLP or an Enhanced PLP. The LDM layer with which a PLP is associated shall be indicated by **L1D_plp_layer**. There shall always be one Core Layer, regardless of whether or not LDM is used. There shall be no Enhanced Layers when LDM is not used. There shall be one or more Enhanced Layers when LDM is used. The current version of the specification shall have a maximum of one Enhanced Layer for LDM.

Each Core PLP within a subframe shall represent one time interleaver group. Each Core PLP shall therefore belong to exactly one time interleaver group within a subframe and shall have directly associated L1 control signaling specifying the time interleaving parameters for that PLP. Each Enhanced PLP shall be associated with one or more time interleaver groups within a subframe and shall not have directly associated L1 control signaling related to time interleaving. An Enhanced PLP shall follow the time interleaving of the time interleaving group(s) with which it is associated. Note that **L1D_plp_start** and **L1D_plp_size** of Enhanced PLPs are defined with respect to before time interleaving.

Time interleaver groups shall be implicitly indexed within a subframe according to the order in which the associated Core PLPs appear in the control signaling for that subframe. That is, the first Core PLP whose parameter set appears in the control signaling for the corresponding subframe shall be indexed as TI_Group_0, the second Core PLP whose parameter set appears in the control signaling for the corresponding subframe shall be indexed as TI_Group_1, and so on. Note that

the implicit indices of and the ordering of the implicit indices of time interleaver groups shall be independent of the **L1D_plp_id** values for Core PLPs present in a subframe.

Time interleaving, cell multiplexing, and subslicing (if applicable) shall be performed based on Core PLPs. An Enhanced PLP shall follow the time interleaving and cell multiplexing of the Core PLP(s) (time interleaver group(s)) with which the Enhanced PLP is associated.

An injection level shall be signaled for each Enhanced PLP. Injection levels shall not be signaled for Core PLPs.

When an Enhanced PLP is layered-division multiplexed with at least one Core PLP that uses the HTI mode, then that Enhanced PLP shall have an integer number of FEC Blocks within each subframe.

When an Enhanced PLP is spread over multiple TI groups, either all Core PLPs associated with that Enhanced PLP shall use the HTI mode or else all Core PLPs associated with that Enhanced PLP shall use the no TI Mode. When all Core PLPs associated with that Enhanced PLP use the HTI mode, each such Core PLP shall use the intra-subframe interleaving mode (i.e., **L1D_plp_HTI_inter_subframe** = 0). When all Core PLPs associated with that Enhanced PLP use the no TI Mode, each such Core PLP shall consist of an integer number of FEC Blocks within each subframe in which that Core PLP is layered-division multiplexed with that Enhanced PLP. This implies that the use of dummy modulation values as described in Section 7.2.6.5 will likely be required in this scenario in order to achieve an integer number of FEC Blocks per subframe.

#### 7.2.7.4.1 Simple LDM Example

Figure 7.18 shows the simplest possible LDM example, with one Core PLP (L1D_PLP_id_0) and one Enhanced PLP (L1D_PLP_id_1), each with the same starting position and length. With only one Core PLP, there is also only one time interleaver group (TI_Group_0). When LDM is applied within a subframe containing only one Core PLP, Convolutional Time Interleaver mode (see Section 7.1.3) may be used.

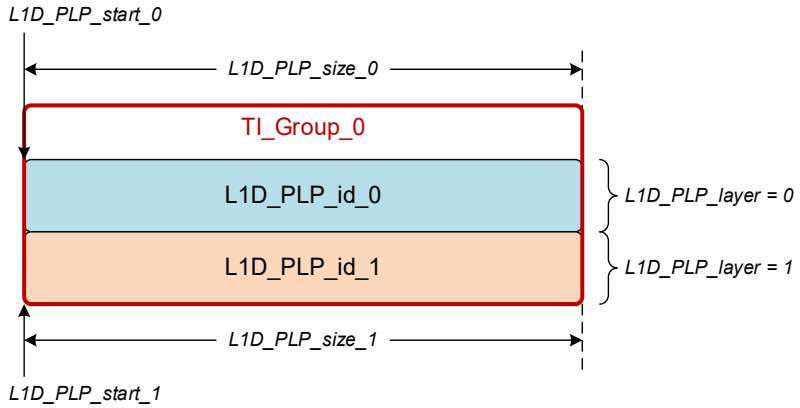


**Figure 7.18** LDM Example #1 (1 Core PLP, 1 Enhanced PLP).

#### 7.2.7.4.2 Two Core PLPs LDM example

Figure 7.19 shows a more complex LDM example, with two Core PLPs (L1D_PLP_id_0 and L1D_PLP_id_1) and one Enhanced PLP (L1D_PLP_id_2). The Enhanced PLP (L1D_PLP_id_2) is exactly aligned with the corresponding Core PLP (L1D_PLP_id_1), with both PLPs having the same start position and length. There are two time interleaver groups (TI_Group_0 and TI_Group_1), one for each Core PLP.

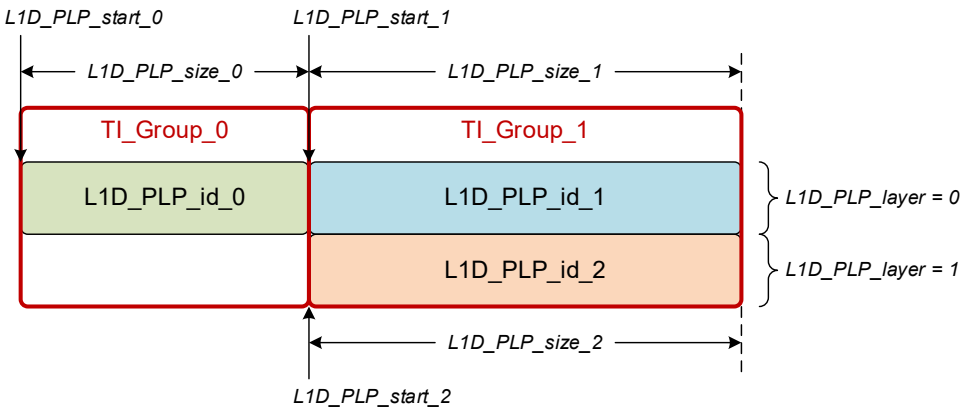


**Figure 7.19** LDM Example #2 (2 Core PLPs, 1 Enhanced PLP).

#### 7.2.7.4.3 Non-aligned Enhanced Layer LDM example

Figure 7.20 shows an LDM example of Enhanced PLPs that are not aligned with Core PLPs. There are two time interleaver groups, one for each Core PLP.

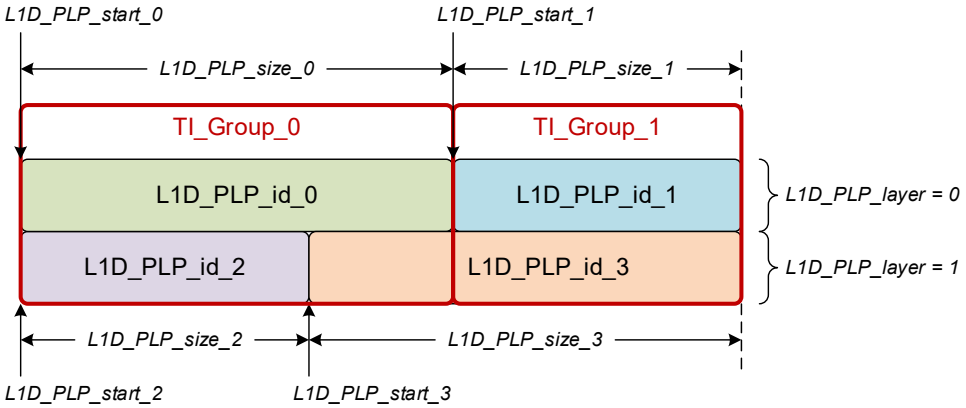


**Figure 7.20** LDM Example #3 (2 Core PLPs, 2 Enhanced PLPs).

L1D_PLP_id_2 is an Enhanced PLP associated with TI_Group_0, which can be easily determined since *L1D_PLP_start_0* and *L1D_PLP_start_2* are equal, and *L1D_PLP_size_2* is less than *L1D_PLP_size_0* (thereby implying that L1D_PLP_id_2 is fully contained within TI_Group_0). L1D_PLP_id_2 is layered-division multiplexed into the first *L1D_PLP_size_2* data cells of TI_Group_0.

L1D_PLP_id_3 is an Enhanced PLP associated with both TI_Group_0 and TI_Group_1. *L1D_PLP_start_3* corresponds to a data cell index that is associated with TI_Group_0, according to the cell multiplexing parameters specified for L1D_PLP_id_0. Since L1D_PLP_id_3 is too long to completely fit into TI_Group_0, L1D_PLP_id_3 automatically continues on into the next implicitly indexed time interleaver group (TI_Group_1).

The first *L1D_PLP_size_0 – L1D_PLP_size_2* data cells of L1D_PLP_id_3 are layered-division multiplexed into the last *L1D_PLP_size_0 – L1D_PLP_size_2* data cells of TI_Group_0. The last *L1D_PLP_size_3 – (L1D_PLP_size_0 – L1D_PLP_size_2)* data cells of L1D_PLP_id_3 are layered-division multiplexed into TI_Group_1.

#### 7.2.7.4.4 Three Enhanced PLPs LDM Example

Figure 7.21 shows an LDM example with one Core PLP (L1D_PLP_id_0) and three Enhanced PLPs (L1D_PLP_id_1, L1D_PLP_id_2, L1D_PLP_id_3), all of which belong to the same time interleaving group (TI_Group_0). *L1D_PLP_start_0* and *L1D_PLP_start_1* are equal. Both *L1D_PLP_start_2* and *L1D_PLP_start_3* correspond to data cell indices that are associated with TI_Group_0, according to the cell multiplexing parameters specified for L1D_PLP_id_0. The sum of the lengths of the three Enhanced PLPs (*L1D_PLP_size_1*, *L1D_PLP_size_2*, *L1D_PLP_size_3*) is equal to the length of the Core PLP (*L1D_PLP_size_0*), so all PLPs fit within the same time interleaving group.

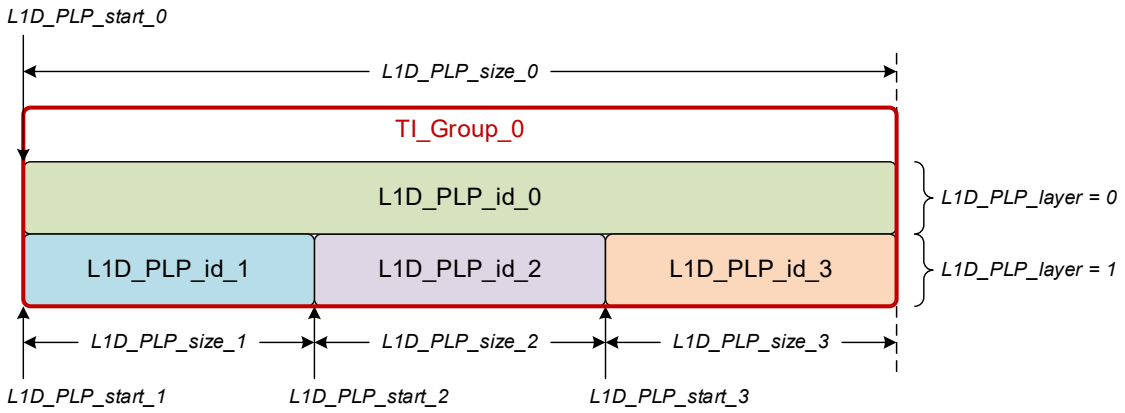


**Figure 7.21** LDM Example #4 (1 Core PLP, 3 Enhanced PLPs).

#### 7.2.7.4.5 Three Core PLPs LDM Example

Figure 7.22 shows an LDM example with three Core PLPs (L1D_PLP_id_0, L1D_PLP_id_1, L1D_PLP_id_2) and one Enhanced PLP (L1D_PLP_id_3). There are three time interleaver groups (TI_Group_0, TI_Group_1, TI_Group_2), one for each of the three Core PLPs.

L1D_PLP_id_3 is an Enhanced PLP associated with all three time interleaver groups. *L1D_PLP_start_3* is equal to *L1D_PLP_start_0*, which implies that the first *L1D_PLP_size_0* data cells of L1D_PLP_id_3 are associated with TI_Group_0. Since L1D_PLP_id_3 is too long to completely fit into TI_Group_0, L1D_PLP_id_3 automatically continues on into the next implicitly indexed time interleaver group (TI_Group_1) and then continues even further into the following implicitly indexed time interleaver group (TI_Group_2). The middle *L1D_PLP_size_1* data cells of L1D_PLP_id_3 are associated with TI_Group_1, and the last *L1D_PLP_size_2* data cells of L1D_PLP_id_3 are associated with TI_Group_2.

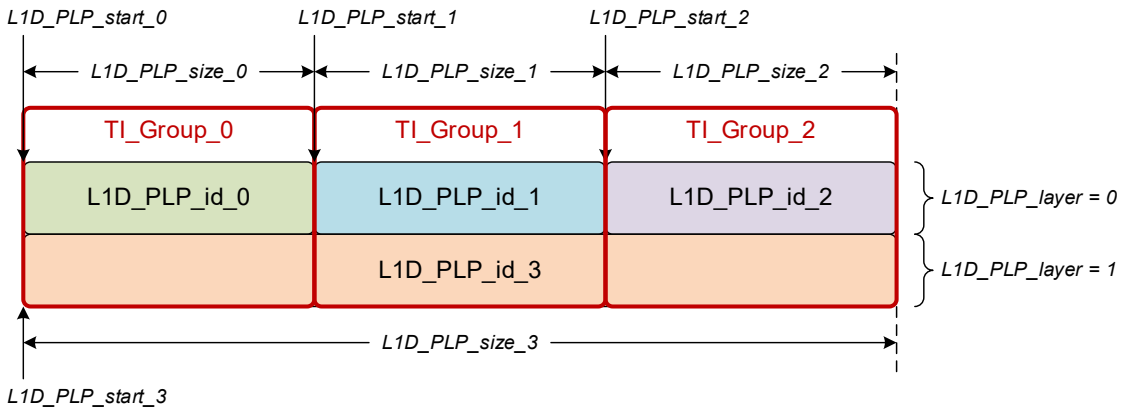


**Figure 7.22** LDM Example #5 (3 Core PLPs, 1 Enhanced PLP).

#### 7.2.7.4.6 Insertion of Enhanced Layer Dummy Modulation Values in HTI Mode with Layered Division Multiplexing

Let a PLP group represent the complete set of PLPs associated with delivering a particular end product to receivers within a subframe. A PLP group will contain at least one Core PLP and will also contain one or more Enhanced PLPs when Layered-Division Multiplexing is in use.

When time interleaving is configured as HTI mode, which uses an integer number of FEC Blocks for the actual PLP data, the total number of cells of Core PLP(s) may be different from that of Enhanced PLP(s) within a particular PLP group depending on ModCod configuration of each PLP. In such cases, Enhanced Layer dummy modulation values shall be inserted after the actual data cells of the last Enhanced PLP in the PLP group so that the total number of Enhanced Layer cells shall be the same as the total number of Core Layer cells in that PLP group as shown in Figure 7.23. Dummy modulation values shall not be inserted in the Core Layer since TI groups are configured with respect to Core PLP(s).

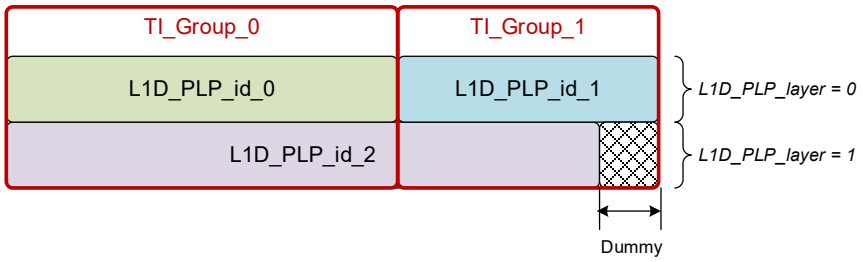


**Figure 7.23** Example Insertion of Enhanced Layer dummy modulation values when the HTI mode is used with Layered-Division Multiplexing.

The insertion of Enhanced Layer dummy modulation values shall be performed after the BICM stages and before Core PLP(s) and Enhanced PLP(s) are combined. For the generation of Enhanced Layer dummy modulation values, the Baseband Packet scrambling sequence defined in Section 5.2.3 shall be used and this scrambling sequence shall be reinitialized for each relevant PLP group.

Then, this sequence shall be modulated by using the same constellation mapping that is used for the last Enhanced PLP in the current PLP group.

The Enhanced Layer dummy modulation values shall have the same power as the immediately preceding Enhanced PLP within the same PLP group so that the same scaling factor and normalizing factor in Table 6.16 are applied for the Enhanced Layer dummy modulation values. Note that when the number of cells allocated to each PLP varies from subframe to subframe due to variable bit rates, the number of Enhanced Layer dummy modulation values would also change from subframe to subframe.

#### 7.2.7.5 Frequency Division Multiplexing (FDM)

The frequency division multiplexing of multiple PLPs within a subframe can be achieved by using dispersed PLPs with appropriate parameter settings. To achieve FDM, the subslice interval of each dispersed PLP is set to the number of data cells per data symbol for the current subframe configuration. The number of subslices is set such that the resulting size of each subslice is less than the number of data cells per data symbol for the current subframe configuration.

Note that the frequency division multiplexing effect can only be achieved if frequency interleaving of the corresponding subframe is disabled. In addition, for full frequency division multiplexing, PLP data cannot be mapped to data cells that belong either to the final Preamble symbol (only applicable for the first subframe of a frame) or to a subframe boundary symbol, since those data cells will not be aligned in frequency with the allocated data cells that belong to a normal data symbol. It may be possible to map PLP data to the final Preamble symbol (for the first subframe of a frame) and/or to a subframe boundary symbol if the limitation of a frequency division multiplexed PLP being mapped to a different portion of the frequency spectrum at the beginning and/or end of a subframe is acceptable. For example, a low-power receiver would have to receive the full system bandwidth of a transmitted signal at the beginning of a frame anyway in order to correctly receive and decode the Preamble (L1-Basic and L1-Detail), so could also receive a frequency division multiplexed PLP that begins in the final Preamble symbol and which is then confined to only a specific portion of the frequency spectrum for the remainder of the subframe (which would thus permit lower-power receiver processing of those data symbols).

Table 7.9 and Figure 7.24 show the cell multiplexing parameters and the resulting graphical view for an example of the frequency division multiplexing of six PLPs. Note that **L1D_plp_num_subslices** is set equal to one less than the number of subslices for a given dispersed PLP (refer to Section 9.3.4), so the actual number of subslices for a dispersed PLP is one more than the number given in Table 7.9.

**Table 7.9** Example Parameters for Frequency Division Multiplexing of PLPs

| L1D_plp_ id | L1D_plp_ size | L1D_plp_ type | L1D_plp_ start | L1D_plp_num _ subslices | L1D_plp_ subslice _interval |
|---|---|---|---|---|---|
| A | 26 | Dispersed | 0 | 25 | 10 |
| B | 52 | Dispersed | 1 | 25 | 10 |
| C | 26 | Dispersed | 3 | 25 | 10 |
| D | 78 | Dispersed | 4 | 25 | 10 |
| E | 26 | Dispersed | 7 | 25 | 10 |
| F | 52 | Dispersed | 8 | 25 | 10 |

Time →

Frequency ↓

| | | | | | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| A00 | A01 | A02 | A03 | A04 | A05 | A06 | A07 | A08 | A09 | A10 | A11 | A12 | A13 | A14 | A15 | A16 | A17 | A18 | A19 | A20 | A21 | A22 | A23 | A24 | A25 |
| B00 | B02 | B04 | B06 | B08 | B10 | B12 | B14 | B16 | B18 | B20 | B22 | B24 | B26 | B28 | B30 | B32 | B34 | B36 | B38 | B40 | B42 | B44 | B46 | B48 | B50 |
| B01 | B03 | B05 | B07 | B09 | B11 | B13 | B15 | B17 | B19 | B21 | B23 | B25 | B27 | B29 | B31 | B33 | B35 | B37 | B39 | B41 | B43 | B45 | B47 | B49 | B51 |
| C00 | C01 | C02 | C03 | C04 | C05 | C06 | C07 | C08 | C09 | C10 | C11 | C12 | C13 | C14 | C15 | C16 | C17 | C18 | C19 | C20 | C21 | C22 | C23 | C24 | C25 |
| D00 | D03 | D06 | D09 | D12 | D15 | D18 | D21 | D24 | D27 | D30 | D33 | D36 | D39 | D42 | D45 | D48 | D51 | D54 | D57 | D60 | D63 | D66 | D69 | D72 | D75 |
| D01 | D04 | D07 | D10 | D13 | D16 | D19 | D22 | D25 | D28 | D31 | D34 | D37 | D40 | D43 | D46 | D49 | D52 | D55 | D58 | D61 | D64 | D67 | D70 | D73 | D76 |
| D02 | D05 | D08 | D11 | D14 | D17 | D20 | D23 | D26 | D29 | D32 | D35 | D38 | D41 | D44 | D47 | D50 | D53 | D56 | D59 | D62 | D65 | D68 | D71 | D74 | D77 |
| E00 | E01 | E02 | E03 | E04 | E05 | E06 | E07 | E08 | E09 | E10 | E11 | E12 | E13 | E14 | E15 | E16 | E17 | E18 | E19 | E20 | E21 | E22 | E23 | E24 | E25 |
| F00 | F02 | F04 | F06 | F08 | F10 | F12 | F14 | F16 | F18 | F20 | F22 | F24 | F26 | F28 | F30 | F32 | F34 | F36 | F38 | F40 | F42 | F44 | F46 | F48 | F50 |
| F01 | F03 | F05 | F07 | F09 | F11 | F13 | F15 | F17 | F19 | F21 | F23 | F25 | F27 | F29 | F31 | F33 | F35 | F37 | F39 | F41 | F43 | F45 | F47 | F49 | F51 |

**Figure 7.24** Example of frequency division multiplexing of PLPs.

#### 7.2.7.6 Time Frequency Division Multiplexing (TFDM)

A mix of time and frequency division multiplexing can be accomplished by applying the approach used to achieve frequency division multiplexing (Section 7.2.7.5) and setting PLP size and subslicing parameters such that the resulting PLP mappings are multiplexed not only in frequency but also in time.

One or more non-dispersed PLPs can also optionally be included in a TFDM subframe.

The same limitations on frequency division multiplexing as described in Section 7.2.7.5 are also applicable to TFDM, although data cells belonging either to the final Preamble symbol or to a subframe boundary symbol could be allocated to a time division multiplexed PLP at either the beginning or end of a subframe, in order to facilitate the full frequency division multiplexing of PLPs within the middle portion of a subframe.

Table 7.10 and Figure 7.25 show the cell multiplexing parameters and the resulting graphical view for an example of the time and frequency division multiplexing of six PLPs. Note that **L1D_plp_num_subslices** is set equal to one less than the number of subslices for a given dispersed PLP (refer to Section 9.3.4), so the actual number of subslices for a dispersed PLP is one more than the number given in Table 7.10.

**Table 7.10** Example Parameters for Time and Frequency Division Multiplexing of PLPs

| L1D_plp_ id | L1D_plp_ size | L1D_plp_ type | L1D_plp_ start | L1D_num _ subslices | L1D_subslice _ interval |
|---|---|---|---|---|---|
| A | 50 | Non-dispersed | 0 | *N/A* | *N/A* |
| B | 33 | Dispersed | 50 | 10 | 10 |
| C | 42 | Dispersed | 53 | 20 | 10 |
| D | 20 | Dispersed | 55 | 3 | 10 |
| E | 85 | Dispersed | 95 | 16 | 10 |
| F | 30 | Dispersed | 160 | 9 | 10 |

Time →

Frequency ↓

| | | | | | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| A00 | A10 | A20 | A30 | A40 | B00 | B03 | B06 | B09 | B12 | B15 | B18 | B21 | B24 | B27 | B30 | F00 | F03 | F06 | F09 | F12 | F15 | F18 | F21 | F24 | F27 |
| A01 | A11 | A21 | A31 | A41 | B01 | B04 | B07 | B10 | B13 | B16 | B19 | B22 | B25 | B28 | B31 | F01 | F04 | F07 | F10 | F13 | F16 | F19 | F22 | F25 | F28 |
| A02 | A12 | A22 | A32 | A42 | B02 | B05 | B08 | B11 | B14 | B17 | B20 | B23 | B26 | B29 | B32 | F02 | F05 | F08 | F11 | F14 | F17 | F20 | F23 | F26 | F29 |
| A03 | A13 | A23 | A33 | A43 | C00 | C02 | C04 | C06 | C08 | C10 | C12 | C14 | C16 | C18 | C20 | C22 | C24 | C26 | C28 | C30 | C32 | C34 | C36 | C38 | C40 |
| A04 | A14 | A24 | A34 | A44 | C01 | C03 | C05 | C07 | C09 | C11 | C13 | C15 | C17 | C19 | C21 | C23 | C25 | C27 | C29 | C31 | C33 | C35 | C37 | C39 | C41 |
| A05 | A15 | A25 | A35 | A45 | D00 | D05 | D10 | D15 | E00 | E05 | E10 | E15 | E20 | E25 | E30 | E35 | E40 | E45 | E50 | E55 | E60 | E65 | E70 | E75 | E80 |
| A06 | A16 | A26 | A36 | A46 | D01 | D06 | D11 | D16 | E01 | E06 | E11 | E16 | E21 | E26 | E31 | E36 | E41 | E46 | E51 | E56 | E61 | E66 | E71 | E76 | E81 |
| A07 | A17 | A27 | A37 | A47 | D02 | D07 | D12 | D17 | E02 | E07 | E12 | E17 | E22 | E27 | E32 | E37 | E42 | E47 | E52 | E57 | E62 | E67 | E72 | E77 | E82 |
| A08 | A18 | A28 | A38 | A48 | D03 | D08 | D13 | D18 | E03 | E08 | E13 | E18 | E23 | E28 | E33 | E38 | E43 | E48 | E53 | E58 | E63 | E68 | E73 | E78 | E83 |
| A09 | A19 | A29 | A39 | A49 | D04 | D09 | D14 | D19 | E04 | E09 | E14 | E19 | E24 | E29 | E34 | E39 | E44 | E49 | E54 | E59 | E64 | E69 | E74 | E79 | E84 |

**Figure 7.25** Example of time and frequency division multiplexing of PLPs.

### 7.3 Frequency Interleaving

Frequency interleaving shall operate on the data cells of one OFDM symbol. Use of the Frequency Interleaver (FI) for the data and subframe boundary symbols of a particular subframe is optional and is signaled with **L1D_frequency_interleaver**. However, the frequency interleaver shall always be used for Preamble symbols.

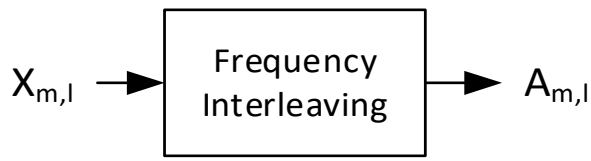


**Figure 7.26** Frequency interleaving overview.

In Figure 7.26 the input cells of the FI (the output cells of the framing) are defined by $X_{m,l} = (x_{m,l,0}, x_{m,l,1}, x_{m,l,2}, \cdots, x_{m,l,N_{data}-1})$, where $x_{m,l,q}$ denotes the cell index $q$ of the symbol $l$ ($l = 0, \ldots, L_{Fm} - 1$) and where $L_{Fm}$ is the number of Preamble, data and subframe boundary symbols in the first subframe ($m$=1) or the number of data and subframe boundary symbols in the second and subsequent subframe ($m > 1$). $N_{data}$ denotes the number of data cells in a symbol as specified in Table 7.2 for Preamble symbols, Table 7.3 and Table 7.4 for data symbols, and Table 7.5 and Table 7.6 for subframe boundary symbols. $A_{m,l} = (a_{m,l,0}, a_{m,l,1}, a_{m,l,2}, \cdots, a_{m,l,N_{data}-1})$ denotes the FI output cells for symbol $l$ of subframe $m$. Note that the counters $l$ used for symbol number and $m$ used for subframe index are unique to this section. In subframe boundary symbols, the frequency interleaver shall operate on both null and active cells.

Figure 7.27, Figure 7.28 and Figure 7.29 show the FI address generator diagrams for the 8K, 16K, and 32K FFT sizes, respectively. Each FI address generator consists of three generation blocks: the (MSB) toggle (T) block, an interleaving sequence generator with a wire permutation, and a symbol offset generator. The address-check block validates whether the generated address is within the range of the allowable carrier indices for the particular OFDM symbol being frequency interleaved.

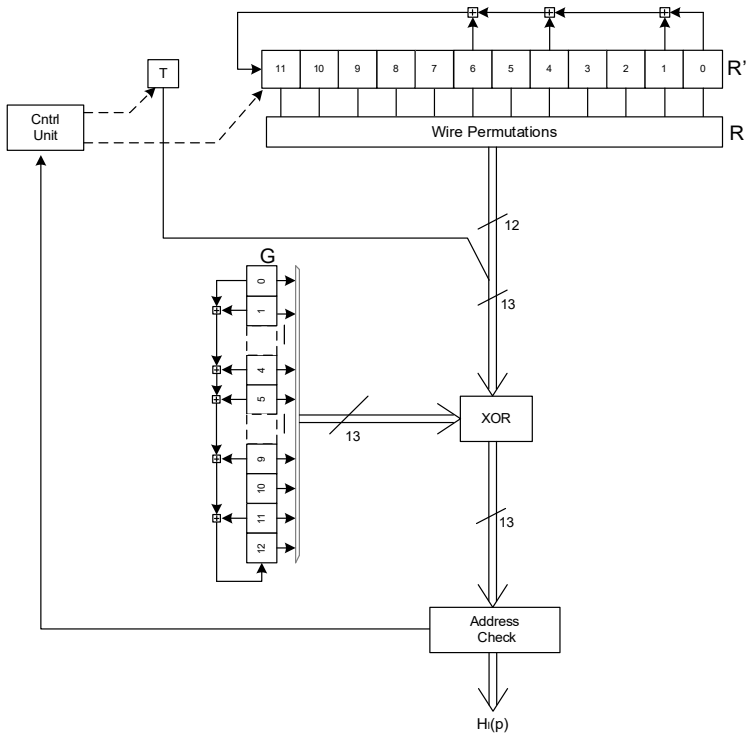


**Figure 7.27** FI address generation scheme for the 8K FFT size.

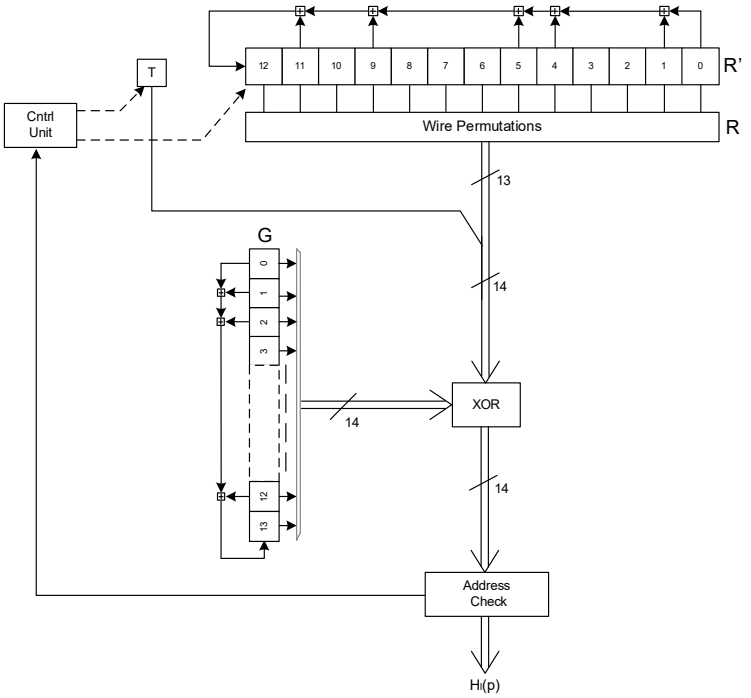


**Figure 7.28** FI address generation scheme for the 16K FFT size.

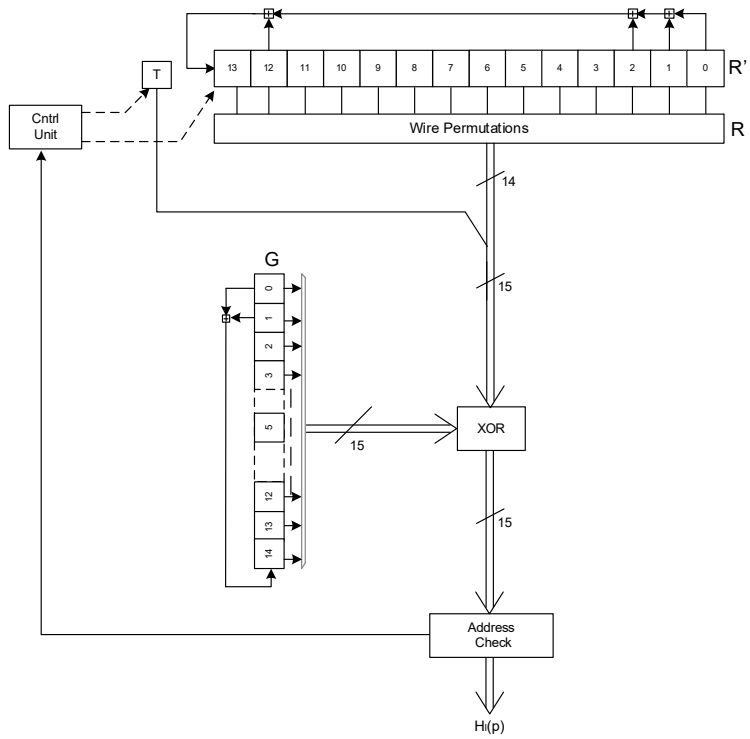


**Figure 7.29** FI address generation scheme for the 32K FFT size.

In detail, in the interleaving sequence generator, an $N_{r-1}$ bit binary word $R'_i$ shall be generated according to the following procedure:

$i = 0,1$ : $R'_i[N_r - 2, N_r - 3, \cdots, 1,0] = [0,0,\cdots,0,0]$,
$i = 2$ : $R'_i[N_r - 2, N_r - 3, \cdots, 1,0] = [0,0,\cdots,0,1]$,
$2 < i < M_{max}$ : $\{R'_i[N_r - 3, N_r - 4, \cdots, 1,0] = R'_{i-1}[N_r - 2, N_r - 3, \cdots, 2,1]$;
8K FFT size: $R'_i[11] = R'_{i-1}[0] \oplus R'_{i-1}[1] \oplus R'_{i-1}[4] \oplus R'_{i-1}[6]$,
16K FFT size: $R'_i[12] = R'_{i-1}[0] \oplus R'_{i-1}[1] \oplus R'_{i-1}[4] \oplus R'_{i-1}[5] \oplus R'_{i-1}[9] \oplus R'_{i-1}[11]$,
32K FFT size: $R'_i[13] = R'_{i-1}[0] \oplus R'_{i-1}[1] \oplus R'_{i-1}[2] \oplus R'_{i-1}[12]\}$.

where $N_r = \log_2 M_{max}$ and the parameter $M_{max}$is defined in Table 7.11.

**Table 7.11** Values of $M_{max}$ for the Frequency Interleaver

| FFT Size | $M_{max}$ |
|---|---|
| 8K | 8192 |
| 16K | 16384 |
| 32K | 32768 |

The wire permutations for each mode are defined by the relation of bit word $R'_i$ and bit word $R_i$ as shown in Table 7.12, Table 7.13, and Table 7.14.

**Table 7.12** Wire Permutations for the 8K FFT Size

| ***R'i* bit positions** | 11 | 10 | 9 | 8 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| ***Ri* bit positions (*even*)** | 5 | 11 | 3 | 0 | 10 | 8 | 6 | 9 | 2 | 4 | 1 | 7 |
| ***Ri* bit positions (*odd*)** | 8 | 10 | 7 | 6 | 0 | 5 | 2 | 1 | 3 | 9 | 4 | 11 |

**Table 7.13** Wire Permutations for the 16K FFT Size

| ***R'i* bit positions** | 12 | 11 | 10 | 9 | 8 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| ***Ri* bit positions (*even*)** | 8 | 4 | 3 | 2 | 0 | 11 | 1 | 5 | 12 | 10 | 6 | 7 | 9 |
| ***Ri* bit positions (*odd*)** | 7 | 9 | 5 | 3 | 11 | 1 | 4 | 0 | 2 | 12 | 10 | 8 | 6 |

**Table 7.14** Wire Permutations for the 32K FFT Size

| ***R'i* bit positions** | 13 | 12 | 11 | 10 | 9 | 8 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| ***Ri* bit positions** | 6 | 5 | 0 | 10 | 8 | 1 | 11 | 12 | 2 | 9 | 4 | 3 | 13 | 7 |

The symbol offset generator generates a new offset every two symbols, i.e. the symbol offset value is constant for two consecutive symbols ($2n$ and $2n+1$). In the symbol offset generator, an $N_r$bit binary word $G_k$ shall be generated according to the following procedure:

$$k = 0 \ : G_k[N_r - 1, N_r - 2, \cdots, 1, 0] = [1, 1, \cdots, 1, 1],$$
$$0 < k < \lceil L_{Fm}/2 \rceil \quad : \{G_k[N_r - 2, N_r - 3, \cdots, 1, 0] = G_{k-1}[N_r - 1, N_r - 2, \cdots, 2, 1];$$
$$\text{8K FFT size:} \quad G_k[12] = G_{k-1}[0] \oplus G_{k-1}[1] \oplus G_{k-1}[4] \oplus G_{k-1}[5] \oplus G_{k-1}[9] \oplus G_{k-1}[11],$$
$$\text{16K FFT size:} \ G_k[13] = G_{k-1}[0] \oplus G_{k-1}[1] \oplus G_{k-1}[2] \oplus G_{k-1}[12],$$
$$\text{32K FFT size:} \ G_k[14] = G_{k-1}[0] \oplus G_{k-1}[1]\}.$$

where $\oplus$ represents an XOR operation.

From Figure 7.27, Figure 7.28, and Figure 7.29, the interleaving sequence $H_l(p)$ ($p = 0, \cdots, N_{data} - 1$) to interleave the input symbol $X_{m,l}$ shall be generated as follows:

for $(l = 0; l < L_{Fm}; l = l + 1)$
{
$\quad p = 0;$
$\quad$ for $(i = 0; i < M_{max}; i = i + 1)$ {
$\quad\quad H_l(p) = \left[((i \bmod 2)2^{N_r - 1} + \sum_{j=0}^{N_r - 2} R_i[j]2^j) \oplus \sum_{j=0}^{N_r - 1} G_{\lfloor l/2 \rfloor}[j]2^j\right];$
$\quad\quad$ if $(H_l(p) < N_{data})$ $p = p + 1;$}
}

Note that for the 8K and 16K FFT sizes, two different wire permutations are used. For a given symbol $l$ the particular wire permutation used shall depend on the value of ($l$ mod 2) as shown in Table 7.12 and Table 7.13. This indicates that a different interleaving sequence is used every symbol. For the 32K FFT size, a single permutation shall be used as shown in Table 7.14, which indicates a different interleaving sequence is used every symbol pair.

For each FFT size, using the interleaving sequence $H_l(p)$ ($p = 0, \cdots, N_{data} - 1$), the interleaved symbol $A_{m,l} = (a_{m,l,0}, a_{m,l,1}, a_{m,l,2}, \cdots, a_{m,l,N_{data}-1})$ is defined as follows.

For the 32K FFT size, the input-output relation of the FI shall be

$$a_{m,l,H_l(p)} = x_{m,l,p}, \text{ for the even symbol of a symbol pair, } l = 0,2,4, \ldots,$$

$$a_{m,l,p} = x_{m,l,H_l(p)}, \text{ for the odd symbol of a symbol pair, } l = 1,3,5, \ldots.$$

For the 8K and 16K FFT sizes, the input-output relation of the FI shall be

$$a_{m,l,p} = x_{m,l,H_l(p)}, \text{ for any symbol, } l = 0,1,2, \ldots.$$

The following clauses describe how the FI shall operate on a frame basis:

1) On the first Preamble symbol of the frame, the symbol offset generator and the interleaving sequence generator shall be reset, i.e. the contents of the symbol offset generator FBSR *G* shall be set to [1111…11] and the contents of the interleaving sequence generator FBSR *R'* shall be set to [0000…00].
2) With the exception of the first subframe in the frame, on the first symbol of the second and subsequent subframes in the frame the symbol offset generator and the interleaving sequence generator shall be reset, i.e. the contents of the symbol offset generator FBSR *G* shall be set to [1111…11] and the contents of the interleaving sequence generator FBSR *R'* shall be set to [0000…00]. The first symbol of a subframe may be a data symbol or a subframe boundary symbol.

## 8. WAVEFORM GENERATION

The block diagram of the Waveform Generation part is shown in Figure 8.1.

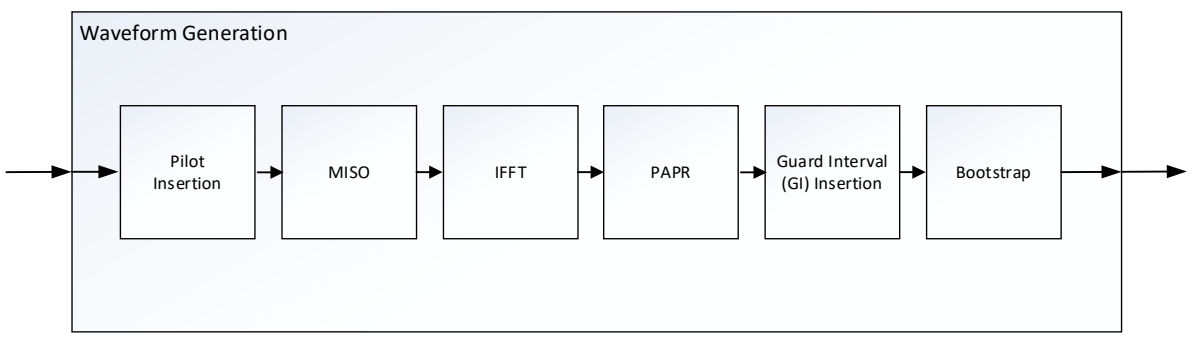


**Figure 8.1** Block diagram of waveform generation.

The waveform generation section consists of pilot insertion in Section 8.1 followed by optional MISO predistortion in Section 8.2. The resultant signal is passed through an IFFT, described in Section 8.3. Optional peak-to-average-power reduction techniques may be applied as described in Section 8.4, followed by guard interval insertion as detailed in Section 8.5. Finally the bootstrap signal is prefixed to the beginning of each frame as shown in Figure 7.10.

## 8.1 Pilot Insertion

### 8.1.1 Introduction

Various cells within the OFDM frame are modulated with reference information whose transmitted value is known to the receiver. Cells containing reference information may be transmitted at a boosted power level. These cells are called scattered, continual, edge, Preamble or subframe boundary pilots. The locations and amplitudes of these pilots are defined in Sections 8.1.3 to Section 8.1.7. The value of the pilot information is derived from a reference sequence, which is a series of values, one for each transmitted carrier on any given symbol, described in Section 8.1.2. The pilots can be used for synchronization, channel estimation, and phase noise estimation, among other uses.

Table 8.1 gives an overview of the different types of pilots and the symbols in which they appear, where a check mark ✔indicates the presence of pilots in that symbol type.

**Table 8.1** Presence of the Various Types of Pilots in Each Type of Symbol

| Symbol Type | Preamble Pilot | Scattered Pilot | Subframe Boundary Pilot | Common Continual Pilot | Additional Continual Pilot | Edge Pilot |
|---|---|---|---|---|---|---|
| Preamble | ✔ | | | ✔ | | |
| Data | | ✔ | | ✔ | ✔ | ✔ |
| Subframe Boundary | | | ✔ | ✔ | ✔ | ✔ |

The following sections specify values for $c_{m,l,k}$, for certain values of $m$, $l$ and $k$, where $m$ and $l$ are the subframe and symbol number, and $k$ is the OFDM carrier index. The symbol number $l$ begins at zero for the first symbol of the Preamble and is incremented every symbol thereafter. The symbol number $l$ is reset to zero at the first symbol in each subframe.

Carrier indices can be considered to be either absolute carrier indices or relative carrier indices. Absolute carrier indices are indexed on the maximum possible number of carriers regardless of whether carrier reduction has been configured and hence range from 0 to $NoC_{max} - 1$. Relative carrier indices are indexed on the configured number of carriers (which is a function in part of the configured carrier reduction coefficient) and hence range from 0 to $NoC - 1$. Preamble, scattered, subframe boundary, edge, and additional continual pilot locations depend on the relative carrier indices. Common continual pilot locations depend on the absolute carrier indices.

### 8.1.2 Reference Sequence

The pilots are modulated according to a reference sequence, $r_k$, where $k$ is the relative carrier index as previously defined. This reference sequence is applied to all the pilots (i.e. scattered, both common and additional continual, edge, Preamble and boundary pilots) of each symbol of a frame. The reference sequence can be generated according to Figure 8.2. The initial sequence shall be 0000 0000 1101 1 and shall be loaded at the start of each symbol.

The generator polynomial $G(x)$ shall be:

$$G(x) = 1+X^9+X^{10}+X^{12}+X^{13}$$

The first 24 values of the reference pilot sequence are 1101 1000 0000 0001 0100 0000.

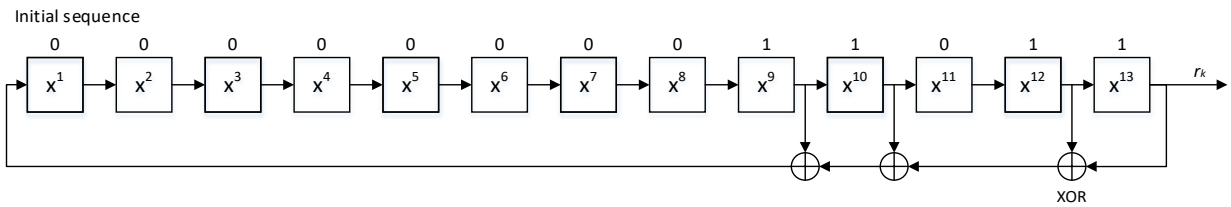


**Figure 8.2** Reference sequence generator.

### 8.1.3 Scattered Pilot Insertion

Reference information, taken from the reference sequence, shall be transmitted in scattered pilot cells in every data symbol. Scattered pilots shall not be transmitted in Preamble symbols and subframe boundary symbols. The locations of the scattered pilots are defined in Section 8.1.3.1, the amplitudes are defined in Section 8.1.3.2 and the modulation is defined in Section 8.1.3.3.

#### 8.1.3.1 Locations of the scattered pilots

A given relative carrier $k$ of the OFDM signal on a given symbol $l$ shall be a scattered pilot if the appropriate equation below is satisfied:

$$k \bmod (D_X D_Y) = D_X (l \bmod D_Y)$$

where: the values of $D_X$ and $D_Y$ are as defined in Table 8.2:

The following definitions apply to the scattered pilots:

$\boldsymbol{D_X}$**:** Separation of pilot bearing carriers (that is, in the frequency direction)

$\boldsymbol{D_Y}$**:** Number of symbols forming one scattered pilot sequence (time direction)

SP***a_b***: pilot pattern designation where $\boldsymbol{a} = D_X$ and $\boldsymbol{b} = D_Y$.

**Table 8.2** Parameters $D_X$ and $D_Y$ Defining the SISO Scattered Pilot Patterns

| Pilot Pattern | $D_X$ | $D_Y$ | Pilot Pattern | $D_X$ | $D_Y$ |
|---|---|---|---|---|---|
| **SP3_2** | 3 | 2 | **SP12_2** | 12 | 2 |
| **SP3_4** | 3 | 4 | **SP12_4** | 12 | 4 |
| **SP4_2** | 4 | 2 | **SP16_2** | 16 | 2 |
| **SP4_4** | 4 | 4 | **SP16_4** | 16 | 4 |
| **SP6_2** | 6 | 2 | **SP24_2** | 24 | 2 |
| **SP6_4** | 6 | 4 | **SP24_4** | 24 | 4 |
| **SP8_2** | 8 | 2 | **SP32_2** | 32 | 2 |
| **SP8_4** | 8 | 4 | **SP32_4** | 32 | 4 |

The combinations of scattered pilot patterns, FFT size and guard interval which shall be allowed are defined in Table 8.3. *N/A* indicates a FFT size/ GI combination that has no valid scattered pilot pattern.

**Table 8.3** Allowed Scattered Pilot Pattern for Each Combination of FFT Size and Guard Interval Pattern in SISO Mode

| GI Pattern | Samples | 8K FFT | 16K FFT | 32K FFT |
|---|---|---|---|---|
| GI1_192 | 192 | SP32_2, SP32_4, SP16_2, SP16_4 | SP32_2, SP32_4 | SP32_2 |
| GI2_384 | 384 | SP16_2, SP16_4, SP8_2, SP8_4 | SP32_2, SP32_4, SP16_2, SP16_4 | SP32_2 |
| GI3_512 | 512 | SP12_2, SP12_4, SP6_2, SP6_4 | SP24_2, SP24_4, SP12_2, SP12_4 | SP24_2 |
| GI4_768 | 768 | SP8_2, SP8_4, SP4_2, SP4_4 | SP16_2, SP16_4, SP8_2, SP8_4 | SP32_2, SP16_2 |
| GI5_1024 | 1024 | SP6_2, SP6_4, SP3_2, SP3_4 | SP12_2, SP12_4, SP6_2, SP6_4 | SP24_2, SP12_2 |
| GI6_1536 | 1536 | SP4_2, SP4_4 | SP8_2, SP8_4, SP4_2, SP4_4 | SP16_2, SP8_2 |
| GI7_2048 | 2048 | SP3_2, SP3_4 | SP6_2, SP6_4, SP3_2, SP3_4 | SP12_2, SP6_2 |
| GI8_2432 | 2432 | *N/A* | SP6_2, SP6_4, SP3_2, SP3_4 | SP12_2, SP6_2 |
| GI9_3072 | 3072 | *N/A* | SP4_2, SP4_4 | SP8_2, SP3_2 |
| GI10_3648 | 3648 | *N/A* | SP4_2, SP4_4 | SP8_2, SP3_2 |
| GI11_4096 | 4096 | *N/A* | SP3_2, SP3_4 | SP6_2, SP3_2 |
| GI12_4864 | 4864 | *N/A* | *N/A* | SP6_2, SP3_2 |

The scattered pilot patterns are illustrated in Annex E.

#### 8.1.3.2 Amplitudes of the Scattered Pilots

The amplitude of the scattered pilots, $A_{SP}$, shall be determined from the parameter **L1D_scattered_pilot_boost** and the scattered pilot pattern. The range of **L1D_scattered_pilot_boost** is defined from 0 to 4. Approximate amplitude values are listed in Table 9.15 and any amplitude value shall be calculated from the exact power values listed in Table 9.14.

#### 8.1.3.3 Modulation of the Scattered Pilots

The phases of the scattered pilots are derived from the reference sequence given in Section 8.1.2.

The modulation value of the scattered pilots shall be given by:

$$\mathrm{Re}\{c_{m,l,k}\} = 2\, A_{SP}\, (1/2 - r_k)$$

$$\mathrm{Im}\{\, c_{m,l,k} \,\} = 0$$

where $A_{SP}$ is as defined in Section 8.1.3.2, $r_k$ is defined in Section 8.1.2, $m$ is the subframe index, $k$ is the relative index of the carriers and $l$ is the time index of the symbols.

### 8.1.4 Continual Pilot Insertion

In addition to the scattered pilots, a number of continual pilots (CP) are inserted in every symbol of the frame, including the Preamble symbols and any subframe boundary symbols. The location of the continual pilots is described in Section 8.1.4.1, the amplitude is described in Section 8.1.4.2 and the modulation is described in Section 8.1.4.3.

#### 8.1.4.1 Locations of the Continual Pilots

Continual pilot locations shall be determined from a common CP set with additional locations from an additional CP set.

The common continual pilot locations for 32K shall be as described in Table D.1.1 and are called the common CP set $CP_{32}$. The locations of the common CPs have been chosen such that they do not fall on scattered pilot (SP) locations. The locations of the common CPs do not depend on the SP pattern.

The common continual pilot locations for 8K and 16K FFT sizes shall be derived from the locations of the common CP set $CP_{32}$ using the following equations:

$$CP_{16}(k') = \lceil CP_{32}(2k')/2 \rceil$$
$$CP_{8}(k'') = \lceil CP_{32}(4k'')/4 \rceil$$

for $k' = 0, 1, \ldots, 95$ and $k'' = 0, 1, \ldots, 47$ where the brackets denote the ceiling operation.

As well as the common CPs (which do not occur on SP carrier locations), a very small number of additional CPs shall be added at carrier locations that may be SP locations as described in Table D.1.4. The reason for the additional CPs is to ensure a constant number of data carriers in every data symbol, since the number of data carriers varies due to the differing number of SPs per symbol. The additional CP sets therefore depend on the scattered pilot patterns as well as the FFT size.

If the bandwidth of the total signal is reduced, that is, $C_{red_coeff} > 0$, any CP positions which fall outside of the number of carriers $NoC$ as defined in Table 7.1 shall be ignored.

The total number of common continual pilots for each FFT size and value of $C_{red_coeff}$ are defined in Table 8.4.

**Table 8.4** Number of Common Continual Pilots in Each FFT Size

| $C_{red_coeff}$ | 8K | 16K | 32K |
|---|---|---|---|
| 0 | 48 | 96 | 192 |
| 1 | 48 | 96 | 192 |
| 2 | 47 | 93 | 186 |
| 3 | 46 | 92 | 184 |
| 4 | 45 | 90 | 180 |

#### 8.1.4.2 Amplitudes of the Continual Pilots

The common continual pilots shall be transmitted at boosted power levels, where the boosting depends on the FFT size. Table 8.5 gives the modulation amplitude $A_{CP}$ of the common continual pilots for each FFT size. The dB values are exact, the linear values are approximate and this is shown by the use of italics.

**Table 8.5** Boosting for the Common Continual Pilots

| FFT size | 8K | 16K | 32K |
|---|---|---|---|
| $A_{CP}$ | *2.67* | *2.67* | *2.67* |
| $A_{CP}$ *(dB)* | 8.52 | 8.52 | 8.52 |

For additional continual pilots, the modulation amplitude of the scattered pilot pattern ($A_{SP}$) shall be used.

#### 8.1.4.3 Modulation of the Continual Pilots

The phases of the continual pilots shall be derived from the reference sequence $r_k$ given in Section 8.1.2. The modulation value for the continual pilots shall be given by:

$$\mathrm{Re}\{c_{m,l,k}\} = 2\, A_{\mathrm{CP}}\, (1/2 - r_k)$$

$$\mathrm{Im}\{\, c_{m,l,k}\, \} = 0.$$

where $A_{\mathrm{CP}}$ is as defined in Table 8.5.

### 8.1.5 Edge Pilot Insertion

The edge carriers, that is carriers with the relative carrier indices $k = 0$ and $k = NoC - 1$, shall be edge pilots in every symbol except for the Preamble symbol(s). Edge pilots are inserted in order to allow frequency interpolation up to the edge of the spectrum. The modulation of these cells shall be exactly the same as for the scattered pilots, as defined in Section 8.1.3.3:

$$\mathrm{Re}\{c_{m,l,k}\} = 2\, A_{\mathrm{SP}}\, (1/2 - r_k)$$

$$\mathrm{Im}\{\, c_{m,l,k}\, \} = 0.$$

### 8.1.6 Preamble Pilot Insertion

The $D_{\mathrm{X}}$ value used for the Preamble pilots of a frame shall be less than or equal to the $D_{\mathrm{X}}$ value used for the scattered pilots of the first subframe of the same frame, in order to provide more accurate equalization for the Preamble symbols.

#### 8.1.6.1 Locations of the Preamble Pilots

Preamble pilots shall always use $D_{\mathrm{Y}} = 1$, that is the pilots shall occur in the same locations for each Preamble symbol. The $D_{\mathrm{X}}$ value of the Preamble pilots shall be signaled by **preamble_structure** in the bootstrap. Details of the valid $D_{\mathrm{X}}$ values for **preamble_structure** are described in Table H.1.1 of Annex H.

The cells in a Preamble symbol for which the relative carrier index $k \bmod D_{\mathrm{X}} = 0$, shall be Preamble pilots.

#### 8.1.6.2 Amplitudes of the Preamble Pilots

The pilot cells in the Preamble symbol(s) shall be transmitted at boosted power levels as shown in Table 8.6, which gives the exact power (in dB) and the corresponding approximate equivalent modulation amplitude $A_{\mathrm{Preamble}}$ for the Preamble pilots.

**Table 8.6** Exact Power (dB) and Approximate Amplitudes of the Preamble Pilots

| FFT Size | GI Length (samples) | Pilot Pattern ($D_x$) | Power (dB) | Equivalent Amplitude ($A_{Preamble}$) |
|---|---|---|---|---|
| 8K | 192 | 16 | 5.30 | *1.841* |
| 8K | 384 | 8 | 3.60 | *1.514* |
| 8K | 512 | 6 | 2.90 | *1.396* |
| 8K | 768 | 4 | 1.80 | *1.230* |
| 8K | 1024 | 3 | 0.90 | *1.109* |
| 8K | 1536 | 4 | 1.80 | *1.230* |
| 8K | 2048 | 3 | 0.90 | *1.109* |
| 16K | 192 | 32 | 6.80 | *2.188* |
| 16K | 384 | 16 | 5.30 | *1.841* |
| 16K | 512 | 12 | 4.60 | *1.698* |
| 16K | 768 | 8 | 3.60 | *1.514* |
| 16K | 1024 | 6 | 2.90 | *1.396* |
| 16K | 1536 | 4 | 2.10 | *1.274* |
| 16K | 2048 | 3 | 1.30 | *1.161* |
| 16K | 2432 | 3 | 1.30 | *1.161* |
| 16K | 3072 | 4 | 2.10 | *1.274* |
| 16K | 3648 | 4 | 2.10 | *1.274* |
| 16K | 4096 | 3 | 1.30 | *1.161* |
| 32K | 192 | 32 | 6.80 | *2.188* |
| 32K | 384 | 32 | 6.80 | *2.188* |
| 32K | 512 | 24 | 6.20 | *2.042* |
| 32K | 768 | 16 | 5.30 | *1.841* |
| 32K | 1024 | 12 | 4.60 | *1.698* |
| 32K | 1536 | 8 | 4.00 | *1.585* |
| 32K | 2048 | 6 | 3.20 | *1.445* |
| 32K | 2432 | 6 | 3.20 | *1.445* |
| 32K | 3072 | 8 | 4.00 | *1.585* |
| 32K | 3072 | 3 | 1.30 | *1.161* |
| 32K | 3648 | 8 | 4.00 | *1.585* |
| 32K | 3648 | 3 | 1.30 | *1.161* |
| 32K | 4096 | 3 | 1.30 | *1.161* |
| 32K | 4864 | 3 | 1.30 | *1.161* |

#### 8.1.6.3 Modulation of the Preamble Pilots

The phases of the Preamble pilots shall be derived from the reference sequence given in Section 8.1.2.

The corresponding modulation shall be given by:

$$\mathrm{Re}\{c_{m,l,k}\} = 2\, A_{\mathrm{Preamble}}\, (1/2 - r_k)$$

$$\mathrm{Im}\{c_{m,l,k}\} = 0$$

where $m$ is the subframe index, $k$ is the frequency index of the carriers and $l$ is the symbol index.

#### 8.1.7 Subframe Boundary Pilot Insertion

The pilots for subframe boundary symbols are denser than for the adjacent normal data symbols of the same subframe.

##### 8.1.7.1 Locations of the Subframe Boundary Pilots

The cells in a subframe boundary symbol for which the relative carrier indices $k$ mod $D_X = 0$, except when $k = 0$ and $k = NoC - 1$, shall be subframe boundary pilots, where $D_X$ is the value from Table 8.2 for the scattered pilot pattern in use for that subframe. Cells in a subframe boundary symbol for which $k = 0$ or $k = NoC - 1$ shall be edge pilots, see Section 8.1.5.

##### 8.1.7.2 Amplitudes of the Subframe Boundary Pilots

The subframe boundary pilots shall be boosted by the same factor as the scattered pilots, $A_{SP}$.

##### 8.1.7.3 Modulation of the Subframe Boundary Pilots

The phases of the subframe boundary pilots shall be derived from the reference sequence given in Section 8.1.2. The corresponding modulation shall be given by:

$$\mathrm{Re}\{c_{m,l,k}\} = 2\, A_{SP}\, (1/2 - r_k)$$

$$\mathrm{Im}\{c_{m,l,k}\} = 0$$

where $m$ is the subframe index, $k$ is the relative carrier index of the carriers and $l$ is the time index of the symbols.

### 8.2 MISO

#### 8.2.1 Transmit Diversity Code Filter Sets

The Transmit Diversity Code Filter Set is a MISO pre-distortion technique that artificially decorrelates signals from multiple transmitters in a Single Frequency Network in order to minimize potential destructive interference. The linear frequency domain filters are all-pass filters with minimized cross-correlation under the constraints of the number of transmitters $N_{TX} \in \{2,3,4\}$ and the time domain span of the filters $N_{MISO} \in \{64,256\}$.

MISO shall be applied only to subframe OFDM symbols and shall not be applied to the bootstrap or Preamble. The use of MISO shall be signaled with the parameters **L1B_first_sub_miso** and **L1D_miso** on a per subframe basis.

Figure 8.3 shows a multi-transmitter system where the $N_{TX}$ pre-distortion filters shall be applied in the frequency domain on the OFDM symbols of each subframe.

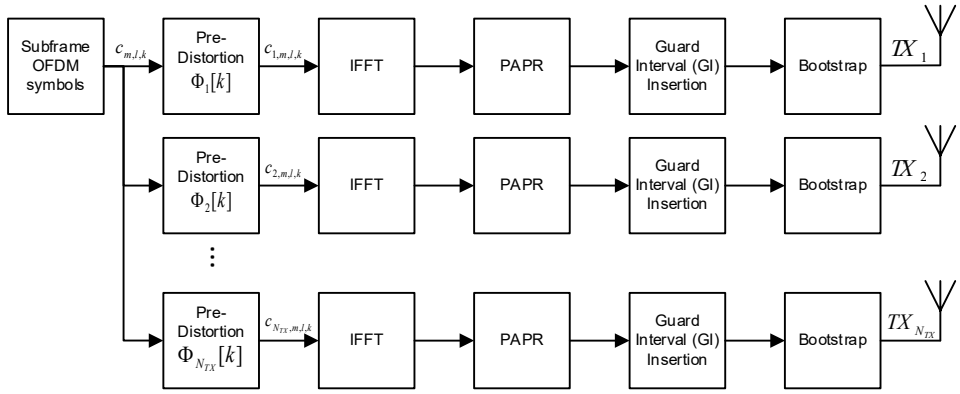


**Figure 8.3** Block diagram showing example MISO transmission.

Code filter frequency domain pre-distortion function $\Phi_x[k]$ shall be determined using the Time Domain Impulse Response Vectors from Table J.1.1 and Table J.1.2 and using a zero-padded FFT of size $N_{FFT}^m$ associated with current subframe $m$:

$$\Phi_x[k] = \exp\left[j \arg\left(\sum_{n=0}^{N_{MISO}-1} h_x[n] e^{-\frac{j2\pi kn}{N_{FFT}^m}}\right)\right];\ k \in \{0, \dots, NoC-1\}, x \in \{1, \dots, N_{TX}\}$$

where exp() represents the natural exponentiation function and arg() represents the argument function which provides the angle in radians of a complex value.

Function $\Phi_x[k]$ shall be applied as:

$$c_{x,m,l,k} = \Phi_x[k] c_{m,l,k};\ k \in \{0, \dots, NoC-1\}, x \in \{1, \dots, N_{TX}\}$$

where:

- $k$ denotes the carrier number;
- $l$ denotes the OFDM symbol index which shall start from 0 at the first OFDM symbol of each subframe;
- $m$ denotes the subframe index, $0 \le m < N_{SF}$;
- $x$ denotes the transmitter index, $x \in \{1, \dots, N_{TX}\}$;
- $c_{m,l,k}$ is the complex modulation value for carrier $k$ of the OFDM symbol number $l$ in subframe number $m$;
- $c_{x,m,l,k}$ is the post-MISO complex modulation value for carrier $k$ of the OFDM symbol index $l$ in subframe index $m$ for transmitter index $x$.

## 8.3 Inverse Fast Fourier Transform (IFFT)

The transmitted signal is organized into frames, and each frame further divided into a bootstrap, Preamble symbol(s) and subframe(s). This section specifies the OFDM structure of the Preamble and subframe symbols.

The subframes in a frame shall be numbered from 0 to $m$. Each subframe $m$ has a duration of $T_{SFm}$, and consists of $L_{SFm}$ OFDM symbols.

The Preamble symbols in a frame shall be numbered from 0 to $L_{Fp}$-1.

The data and subframe boundary symbols in OFDM subframe $m$ shall be numbered from 0 to $L_{SFm}$-1. All symbols shall contain both data and reference information (i.e. pilots).

Each symbol is constituted by a set of $NoC$ carriers transmitted with a duration $T_{Sm}$. Each symbol is composed of two parts: a useful part with duration $T_{Um}$ and a guard interval with duration $T_{Gm}$. The guard interval consists of a cyclic continuation of the useful part, $T_{Um}$, which shall be inserted before it. The allowed combinations of FFT size and guard interval are defined in Table 8.9.

Since the OFDM signal comprises many separately-modulated carriers, each symbol can in turn be considered to be divided into cells, each corresponding to the modulation carried on one carrier during one symbol.

The carriers are indexed by $k \in [0; NoC - 1]$. The spacing between adjacent carriers is $1/T_U$ while the spacing between carriers 0 and $NoC$-1 is determined by $(NoC\text{-}1)/T_U$.

The baseband time domain signal after IFFT shall be described by the following expression:

$$\sum_{l=0}^{L_{Fp}-1} \frac{1}{\sqrt{P_{preamble,l}}} \sum_{k=0}^{NoC_{P,l}-1} c_{l,k} \times \psi_{l,k}(t) + \sum_{m=0}^{N_{SF}-1} \frac{1}{\sqrt{P_{data,m}}} \sum_{l=0}^{L_{SFm}-1} \sum_{k=0}^{NoC_m-1} c_{m,l,k} \times \psi_{m,l,k}(t)$$

where:

$$\psi_{l,k}(t) = \begin{cases} e^{j2\pi \frac{k'}{T_{Up}}(t - T_{BS} - T_{Gp} - lT_{Sp})} & T_{BS} + lT_{Sp} \le t < T_{BS} + (l+1)T_{Sp} \\ 0 & \text{otherwise} \end{cases},$$

$$\psi_{m,l,k}(t) = \begin{cases} e^{j2\pi \frac{k'}{T_{Um}}(t - T_{BS} - T_P - T_{Gm} - lT_{Sm} - \sum T_{SFm})} & T_{BS} + T_P + \sum T_{SFm} + lT_{Sm} \le t < T_{BS} + T_P + \sum T_{SFm} + (l+1)T_{Sm} \\ 0 & \text{otherwise} \end{cases}$$

and:

- $k$ denotes the carrier number;
- $l$ denotes the OFDM symbol number starting from 0 for the first Preamble symbol of a frame and being reset at the first OFDM symbol of each subframe;
- $m$ denotes the subframe number, $0 \le m < N_{SF}$;
- $k'$ is the carrier index relative to the center frequency, $k' = k - (NoC - 1) / 2$;
- $c_{l,k}$ is the complex modulation value for carrier $k$ of the Preamble symbol number $l$;
- $c_{m,l,k}$ is the complex modulation value for carrier $k$ of the OFDM symbol number $l$ in subframe number $m$;
- $NoC_{P,l}$ denotes the number of carriers in the $(l + 1)^{th}$ Preamble symbol. The first Preamble symbol ($l = 0$) always has the minimum NoC and the following Preamble symbols ($0 < l < L_{Fp}$) share the same NoC value that is signaled in L1-Basic as explained in Sections 7.2.5.1 and 9.2.2;
- $NoC_m$ denotes the number of carriers of subframe $m$ as defined in Table 8.8;

$L_{SFm}$ is the number of data and subframe boundary symbols in subframe $m$;

$L_{Fp}$ is the number of OFDM symbols in the Preamble;

$T_{Sm}$ is the total symbol duration of each data and subframe boundary symbol in subframe $m$, and $T_{Sm} = T_{Um} + T_{Gm}$;

$T_{Um}$ is the useful symbol duration for each data and subframe boundary symbol in subframe $m$, defined in Table 8.8;

$T_{Gm}$ is the duration of the guard interval for each data and subframe boundary symbol in subframe $m$ including extra samples for each data and subframe boundary symbol as defined in Section 8.5;

$T_{BS}$ is the duration of the bootstrap;

$T_P$ is the total duration of the Preamble, where $T_P = L_{Fp}\, T_{Sp}$;

$T_{Sp}$ is the total symbol duration of each Preamble symbol and $T_{Sp} = T_{Up} + T_{Gp}$;

$T_{Up}$ is the useful symbol duration for each Preamble symbol;

$T_{Gp}$ is the duration of the guard interval for each Preamble symbol;

$T_{SFm}$ is the total duration of all data and subframe boundary symbols in subframe $m$;

$\sum T_{SFm}$ is the summation of the total duration of subframes from 0 to $m$-1, $\sum T_{SFm} = \sum_0^{m-1} T_{SFm}$, $\sum T_{SFm} = 0$ if $m = 0$;

$N_{SF}$ is the number of subframes in a frame;

$P_{Preamble,l}$ is the frequency domain total power of the $(l + 1)^{th}$ Preamble symbol;

$P_{data,m}$ is the frequency domain total power of each data and subframe boundary symbol in subframe $m$.

The IFFT power normalization factor shall be used to normalize the average power of the baseband time domain signal to one regardless of the waveform parameters in use. Because the OFDM symbol power before power normalization varies significantly depending on the waveform parameters such as FFT size, scattered pilot pattern, amplitude of the scattered pilots, and the number of carriers, different IFFT power normalization factors shall be used for different settings of waveform parameters. The IFFT power normalization factor for the Preamble, $1/\sqrt{P_{preamble,l}}$, can be obtained using the frequency domain total power of the Preamble symbol which is summarized in Table I.1.1. The IFFT power normalization factor for data and subframe boundary symbols, $1/\sqrt{P_{data,m}}$, can be obtained in a similar way using the frequency domain total power of the data and subframe boundary symbol which is summarized in Table I.2.1 to Table I.2.5.

The OFDM parameters are summarized in Table 8.8. The values for the various time-related parameters are given in multiples of the elementary period $T$ and in microseconds. The elementary period $T$ is specified by 1/(0.384MHz × (16+**bsr_coefficient**)), where **bsr_coefficient** is defined in Table 9.1 for each bandwidth, and approximate values for $T$ are shown in Table 8.7 for convenience. The bandwidth of the system is determined from the value of **system_bandwidth** signaled in bootstrap symbol 1. See Section 9.1 for details of the bootstrap.

**Table 8.7** Approximate Elementary Periods $T$

| **bsr_coefficient** | **2** | **5** | **8** |
|---|---|---|---|
| Elementary period $T$ (μs) | *0.1447* | *0.1240* | *0.1085* |

**Table 8.8** OFDM Parameters

| **Parameter** | | **8K FFT** | **16K FFT** | **32K FFT** |
|---|---|---|---|---|
| **Number of carriers *NoC*** | $C_{red_coeff}$ = 0 | 6913 | 13825 | 27649 |
| | $C_{red_coeff}$ = 1 | 6817 | 13633 | 27265 |
| | $C_{red_coeff}$ = 2 | 6721 | 13441 | 26881 |
| | $C_{red_coeff}$ = 3 | 6625 | 13249 | 26497 |
| | $C_{red_coeff}$ = 4 | 6529 | 13057 | 26113 |
| **Duration $T_U$** | | 8192 T | 16384 T | 32768 T |
| **Duration $T_U$ (μs)** (see note 1 and 2) | | *1185.185* | *2370.370* | *4740.741* |
| **Carrier spacing 1/$T_U$ (Hz)** (see note 2) | | 843.75 | 421.875 | 210.9375 |
| **Spacing between carriers 0 and *NoC* – 1 (*NoC*-1)/$T_U$ (MHz)** (see note 2) | $C_{red_coeff}$ = 0 | 5.832 | 5.832 | 5.832 |
| | $C_{red_coeff}$ = 1 | 5.751 | 5.751 | 5.751 |
| | $C_{red_coeff}$ = 2 | 5.670 | 5.670 | 5.670 |
| | $C_{red_coeff}$ = 3 | 5.589 | 5.589 | 5.589 |
| | $C_{red_coeff}$ = 4 | 5.508 | 5.508 | 5.508 |
| Note 1: Numerical values in italics are approximate values.<br>Note 2: Values are for **bsr_coefficient**=2 and **system_bandwidth**=6 MHz. | | | | |

## 8.4 Peak to Average Power Ratio Reduction Techniques

In order to reduce the Peak to Average Power Ratio of the output OFDM signal, modifications to the transmitted OFDM signal—tone reservation described in Section 8.4.1 and Active Constellation Extension (ACE) described in Section 8.4.2—may be used. None, one or both techniques may be used. Guard interval insertion is applied after the PAPR reduction.

### 8.4.1 Tone Reservation

When Tone Reservation (TR) is enabled, some OFDM carriers shall be reserved to allow the insertion of cells designed to reduce the overall PAPR of the output waveform. These cells shall not contain any payload data or signaling information.

The sets of carriers reserved for PAPR reduction in Preamble, data and subframe boundary symbols shall be as defined in Table G.1.2 and Table G.1.3.

Depending on the data OFDM symbol index, the carriers in the tables specified above or the circular shifts of these values are used. The amount of circular shift depends on the pilot spacing $D_X$ and $D_Y$. In a data symbol corresponding to an index $l$, the reserved carrier set $S_l$ shall be calculated as:

$$S_l = i_k + D_X \times (l \bmod D_Y), i_n \in S_0, 0 \le n < N_{TR}, d_0 \le l \le d_{end}$$

where $S_0$ represents the set of reserved carriers corresponding to carrier indices defined in the tables specified above, $N_{TR}$ is the number of reserved cells per OFDM symbol, $d_0$ represents the index of the first OFDM symbol of the subframe and $d_{end}$ represents the index of the last data symbol.

An example algorithm for generating the values inserted into the tone reservation carriers is described in Annex M.2.

### 8.4.2 Active Constellation Extension (ACE)

The Active Constellation Extension (ACE) algorithm reduces the PAPR by the modification of the transmitted constellation points. The active constellation extension technique shall not be applied to pilot carriers or reserved tones. ACE shall not be used in conjunction with LDM, MISO or MIMO.

An example algorithm for ACE is described in Annex M.3.

## 8.5 Guard Interval

In Table 8.9 twelve guard intervals are defined in terms of the absolute guard interval length expressed in samples. Table 8.9 additionally defines with a check mark ✔which guard interval patterns shall be allowed for each FFT size, those guard interval patterns not allowed are shown by *N/A*.

**Table 8.9** Duration of the Guard Intervals in Samples

| GI Pattern | Duration in Samples | 8K FFT | 16K FFT | 32K FFT |
|---|---|---|---|---|
| GI1_192 | 192 | ✔ | ✔ | ✔ |
| GI2_384 | 384 | ✔ | ✔ | ✔ |
| GI3_512 | 512 | ✔ | ✔ | ✔ |
| GI4_768 | 768 | ✔ | ✔ | ✔ |
| GI5_1024 | 1024 | ✔ | ✔ | ✔ |
| GI6_1536 | 1536 | ✔ | ✔ | ✔ |
| GI7_2048 | 2048 | ✔ | ✔ | ✔ |
| GI8_2432 | 2432 | *N/A* | ✔ | ✔ |
| GI9_3072 | 3072 | *N/A* | ✔ | ✔ |
| GI10_3648 | 3648 | *N/A* | ✔ | ✔ |
| GI11_4096 | 4096 | *N/A* | ✔ | ✔ |
| GI12_4864 | 4864 | *N/A* | *N/A* | ✔ |

### 8.5.1 Guard Interval Extension for Time-aligned Frames

The contents of this section shall apply when time-aligned frames are indicated. The contents of this section shall not apply when symbol-aligned frames are indicated.

When a time-aligned frame is indicated, zero or more extra samples in addition to the indicated guard interval (see Table 8.9) shall be inserted to make the total actual frame length equal to the signaled frame length. These extra samples shall be distributed to the specific portions of the non-Preamble OFDM symbols within the frame using the following algorithm. The approach detailed here ensures that all OFDM symbols within a given subframe have the same guard interval length and that an equal number of extra samples are distributed to the guard interval of every non-Preamble OFDM symbol within a frame.

- $T_{bootstrap}$ is the total time length (in seconds) of the bootstrap for the current frame.
- $T_{frame}$ is the indicated total frame time length in seconds.
- $BSR$ is the baseband sampling rate (in MSamples/s) for the non-bootstrap portion of the current frame.
- $N_{symbols}^{preamble}$ is the number of Preamble symbols.
- $N_{FFT}^{preamble}$ is the FFT size of the Preamble symbols.

- $N_{GI}^{preamble}$ is the guard interval length (in samples) for the Preamble symbols.
- $N_{sub}$ is the total number of subframes in the frame.
- $N_{symbols}^{k}$ is the number of OFDM symbols (including any subframe boundary symbols) in the *k*th subframe.
- $N_{FFT}^{k}$ is the FFT size for the *k*th subframe.
- $N_{GI}^{k}$ is the indicated guard interval length (in samples) for the *k*th subframe.
- $N_{extra}$ is the total number of extra samples required to be inserted into a frame in order to make the actual and signaled frame lengths equal. $N_{extra}$ shall be calculated as:

$$N_{extra} = \left(T_{frame} - T_{bootstrap}\right) \times BSR - N_{symbols}^{preamble} \times \left(N_{FFT}^{preamble} + N_{GI}^{preamble}\right) - \sum_{k=1}^{N_{sub}} N_{symbols}^{k} \times \left(N_{FFT}^{k} + N_{GI}^{k}\right)$$

- $N_{symbols} = \sum_{k=1}^{N_{sub}} N_{symbols}^{k}$ is the total number of non-Preamble OFDM symbols contained in the frame (across all $N_{sub}$ subframes).
- The guard interval of each non-Preamble OFDM symbol in the frame shall receive $\mathrm{floor}\left(N_{extra}/N_{symbols}\right)$ extra samples as illustrated in Figure 8.4, where $\mathrm{floor}(x)$ is defined as the largest integer that is less than or equal to $x$.

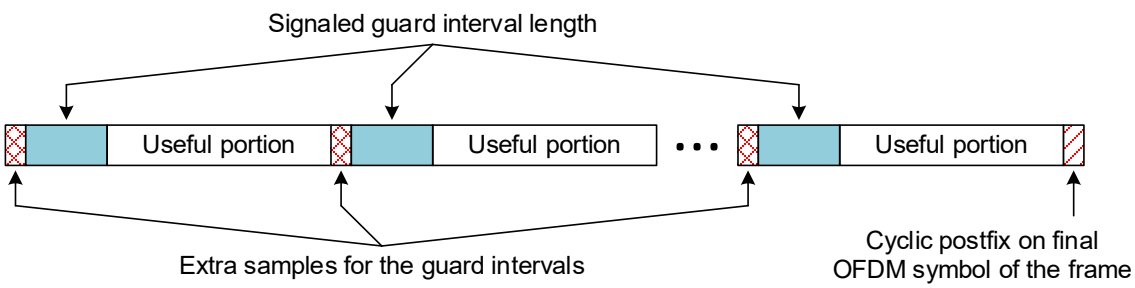


**Figure 8.4** Illustration of the assignment of extra samples to the guard interval of each non-Preamble OFDM symbol in a frame.

- The remaining leftover $N_{extra} \bmod N_{symbols}$ extra samples, if any, shall be inserted immediately following the final OFDM symbol of the final subframe of the frame. These samples shall represent a cyclic postfix of that OFDM symbol consisting of the requisite number of samples copied from the beginning of the useful portion of that OFDM symbol, as illustrated in Figure 8.5.

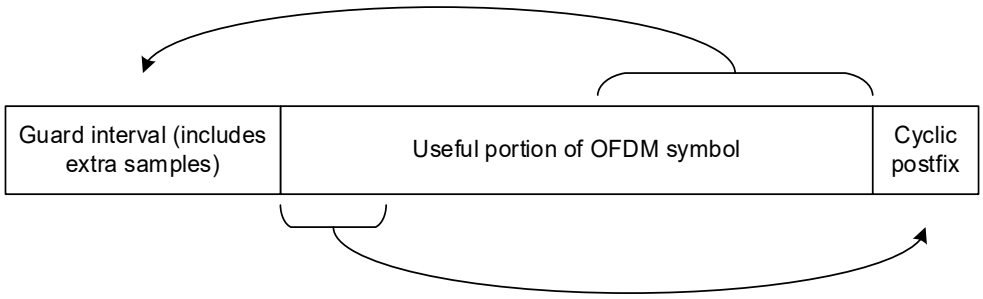


**Figure 8.5** Illustration of remaining leftover extra samples being assigned to a cyclic postfix of the final OFDM symbol of the final subframe of the frame.

### 8.6 Bootstrap

The bootstrap symbol construction is defined in detail in [2]. Section 9.1 establishes constraints on the payload contents of the bootstrap to represent the set of capabilities that this standard supports.

## 9. L1 SIGNALING

L1 signaling provides the necessary information to configure the physical layer parameters. The term 'L1' refers to Layer-1, the lowest layer of the ISO 7 layer model. L1 signaling consists of three parts: constraints on the bootstrap, described in Section 9.1, L1-Basic which is described in Section 9.2 and L1-Detail which is described in Section 9.3. Both L1-Basic and L1-Detail are carried in the Preamble symbols.

L1-Basic conveys the most fundamental signaling information of the system and also defines the parameters needed to decode L1-Detail. The length of L1-Basic signaling is fixed at 200 bits.

L1-Detail details the data context and the required information to decode it. The length of L1-Detail signaling may vary from frame to frame.

Note: Some signaling fields represent quantities for which the actual value zero is not valid (e.g., zero Preamble symbols is not a valid configuration). Therefore, signaling of a value one less than the actual value is used in these cases to maximize the efficiency of the range of values that can be signaled by the number of signaling bits available for each signaling field.

### 9.1 Bootstrap

This section establishes constraints on the payload contents of the bootstrap symbols to represent the set of capabilities that this standard supports. Versioning is defined in Section 9.1.1, and the bootstrap symbol contents are defined in Sections 9.1.2, 9.1.3 and 9.1.4 respectively. Any contents not explicitly defined here shall follow [2].

#### 9.1.1 Versioning

The value of **bootstrap_major_version** as defined by [2] shall be 0.

The value of **bootstrap_minor_version** as defined by [2] shall be 0.

#### 9.1.2 Bootstrap Symbol 1

The constraints and meanings for the contents of bootstrap symbol 1 are completely defined by [2].

### 9.1.3 Bootstrap Symbol 2

The value for the **bsr_coefficient** defined in [2] (part of bootstrap symbol 2) shall be one of the values shown in Table 9.1, and shall be the one that is applicable to the bandwidth of the emission.

**Table 9.1** Defined Values of **bsr_coefficient**

| bsr_coefficient | Applicability |
|---|---|
| 2 | 6 MHz bandwidth |
| 5 | 7 MHz bandwidth |
| 8 | 8 MHz bandwidth |

### 9.1.4 Bootstrap Symbol 3

The value for the **preamble_structure** defined in [2] (bootstrap symbol 3) shall be one of the non-reserved values listed in Table H.1.1.

## 9.2 Syntax for L1-Basic Data

The syntax and field semantics of the L1-Basic signaling fields shall be as defined in Table 9.2 and the following subsections. The names of signaling fields in L1-Basic are always prefixed with '**L1B_**'.

**Table 9.2** L1-Basic Signaling Fields and Syntax

| Syntax | No. of Bits | Format |
|---|---|---|
| L1_Basic_signaling() { | | |
| **L1B_version** | 3 | uimsbf |
| **L1B_mimo_scattered_pilot_encoding** | 1 | uimsbf |
| **L1B_lls_flag** | 1 | uimsbf |
| **L1B_time_info_flag** | 2 | uimsbf |
| **L1B_return_channel_flag** | 1 | uimsbf |
| **L1B_papr_reduction** | 2 | uimsbf |
| **L1B_frame_length_mode** | 1 | uimsbf |
| if ( **L1B_frame_length_mode**=0 ) { | | |
| **L1B_frame_length** | 10 | uimsbf |
| **L1B_excess_samples_per_symbol** | 13 | uimsbf |
| } else { | | |
| **L1B_time_offset** | 16 | uimsbf |
| **L1B_additional_samples** | 7 | uimsbf |
| } | | |
| **L1B_num_subframes** | 8 | uimsbf |
| **L1B_preamble_num_symbols** | 3 | uimsbf |
| **L1B_preamble_reduced_carriers** | 3 | uimsbf |
| **L1B_L1_Detail_content_tag** | 2 | uimsbf |
| **L1B_L1_Detail_size_bytes** | 13 | uimsbf |
| **L1B_L1_Detail_fec_type** | 3 | uimsbf |
| **L1B_L1_Detail_additional_parity_mode** | 2 | uimsbf |
| **L1B_L1_Detail_total_cells** | 19 | uimsbf |
| **L1B_first_sub_mimo** | 1 | uimsbf |
| **L1B_first_sub_miso** | 2 | uimsbf |
| **L1B_first_sub_fft_size** | 2 | uimsbf |

| Syntax | No. of Bits | Format |
|---|---|---|
| **L1B_first_sub_reduced_carriers** | 3 | uimsbf |
| **L1B_first_sub_guard_interval** | 4 | uimsbf |
| **L1B_first_sub_num_ofdm_symbols** | 11 | uimsbf |
| **L1B_first_sub_scattered_pilot_pattern** | 5 | uimsbf |
| **L1B_first_sub_scattered_pilot_boost** | 3 | uimsbf |
| **L1B_first_sub_sbs_first** | 1 | uimsbf |
| **L1B_first_sub_sbs_last** | 1 | uimsbf |
| **L1B_reserved** | 48 | uimsbf |
| **L1B_crc** | 32 | uimsbf |
| } | | |

### 9.2.1 L1-Basic System and Frame Parameters

The following parameters provide information related to the entire frame.

**L1B_version** – This field shall indicate the version of the L1-Basic signaling structure that is used for the current frame. For the current version of the specification **L1B_version** shall be set to 0. It is envisaged that when new L1-Basic signaling fields are introduced into an updated L1-Basic signaling structure in such a manner that the presence or absence of at least one of those new L1-Basic signaling fields cannot be otherwise deduced, **L1B_version** would be incremented by 1. New L1-Basic signaling fields that are introduced into an L1-Basic signaling structure corresponding to a particular **L1B_version** should be added in such a manner that they do not interfere with the parsing of L1-Basic signaling fields by receivers that have been provisioned only up to an earlier **L1B_version**.

**L1B_mimo_scattered_pilot_encoding** – This field shall indicate the appropriate MIMO pilot encoding scheme used by any MIMO subframes in the current frame as given in Table 9.3. When there are no MIMO subframes in the current frame, the value of **L1B_mimo_scattered_pilot_encoding** shall be signaled as 0.

**Table 9.3** Signaling Format for **L1B_mimo_scattered_pilot_encoding**

| Value | Meaning |
|---|---|
| 0 | Walsh-Hadamard pilots or no MIMO subframes |
| 1 | Null pilots |

**L1B_lls_flag** – This field shall indicate the presence or absence of Low Level Signaling (LLS) in one or more PLPs in the current frame. **L1B_lls_flag**=0 shall indicate there is no LLS signaling in the current frame, while **L1B_lls_flag**=1 shall indicate there is LLS signaling carried in this frame. The PLP(s) which carry LLS shall be indicated by **L1D_plp_lls_flag.**

**L1B_time_info_flag** – This field shall indicate the presence or absence of timing information in the current frame, and the precision to which it is signaled according to Table 9.4.

**Table 9.4** Signaling Format for **L1B_time_info_flag**

| Value | Meaning |
|---|---|
| 00 | Time information is not included in the current frame |
| 01 | Time information is included in the current frame and signaled to ms precision |
| 10 | Time information is included in the current frame and signaled to μs precision |
| 11 | Time information is included in the current frame and signaled to ns precision |

**L1B_return_channel_flag** – This field shall indicate whether a dedicated return channel (DRC) is present. Specifically, **L1B_return_channel_flag** = 1 shall indicate that DRC is supported in the current frame of the current frequency band and current broadcast network. **L1B_return_channel_flag** = 0 shall indicate that DRC is not supported in the current frame of the current frequency band and current broadcast network.

**L1B_papr_reduction** – This field shall indicate the technique to reduce the peak to average power ratio within the current frame as given in Table 9.5. The PAPR reduction technique shall apply to all OFDM symbols contained within the current frame, with the exception of the first Preamble symbol. **L1B_papr_reduction**=10 and **L1B_papr_reduction**=11 shall not be indicated when any of the following conditions is satisfied.

- **L1B_first_sub_miso**=01 or **L1B_first_sub_miso**=10 and/or **L1D_miso**=01 or **L1D_miso**=10 for any subframe within the current frame
- **L1B_first_sub_mimo**=1 and/or **L1D_mimo**=1 for any subframe within the current frame
- **L1D_plp_layer>**0 for any PLP within the current frame

**Table 9.5** Signaling Format for **L1B_papr_reduction**

| Value | Meaning |
|---|---|
| 00 | No PAPR reduction used |
| 01 | tone reservation only |
| 10 | ACE only |
| 11 | Both TR and ACE |

**L1B_frame_length_mode** – This field shall be set to **L1B_frame_length_mode**=0 to indicate that the current frame is time-aligned with excess sample distribution to the guard intervals of Data Payload OFDM symbols (i.e. non-Preamble OFDM symbols) as described in Section 8.5.1. The field shall be set to **L1B_frame_length_mode**=1 to indicate that the current frame is symbol-aligned with no excess sample distribution.

**L1B_frame_length** – This field shall only be included when **L1B_frame_length_mode**=0 (i.e. when time-aligned frames are configured) and shall indicate the time period measured from the beginning of the first sample of the bootstrap associated with the current frame to the end of the final sample associated with the current frame (i.e. the signaled frame length also includes the length of the bootstrap). The time period indicated shall be expressed in units of 5 ms (i.e. time period = **L1B_frame_length** × 5 ms). As stated in Section 7.2.2.2, the minimum frame length is 50 ms and the maximum frame length is 5 seconds, which implies that 10 ≤ **L1B_frame_length** ≤ 1000.

**L1B_excess_samples_per_symbol** – This field shall only be included when **L1B_frame_length_mode**=0 (i.e. when time-aligned frames are configured) and shall indicate the additional number of excess samples included in the guard interval of each non-Preamble OFDM symbol of the post-bootstrap portion of the current frame when time-aligned frames are used. The same number of excess samples is included in the guard interval of each and every non-Preamble OFDM symbol of the post-bootstrap portion of a frame according to the excess sample insertion algorithm described in Section 8.5.1. The total length of the guard interval for each OFDM symbol belonging to a particular subframe of the current frame shall be equal to the sum of the guard interval length for that particular subframe (as indicated by **L1B_first_sub_guard_interval** for the first subframe and by the appropriate **L1D_guard_interval** for any subsequent subframes) and the value signaled by **L1B_excess_samples_per_symbol**.

**L1B_time_offset** – This field shall only be included when **L1B_frame_length_mode**=1 (i.e. when symbol-aligned frames are configured) and shall indicate the number of sample periods (using the BSR configured for the current frame) between the nearest preceding or coincident millisecond boundary and the leading edge of the frame.

**L1B_additional_samples** – This field shall only be included when **L1B_frame_length_mode**=1 (i.e. when symbol-aligned frames are configured) and shall indicate the number of additional samples added at the end of a frame to facilitate sampling clock alignment. For the current version of the specification, **L1B_additional_samples** shall be set to 0 when present.

**L1B_num_subframes** – This field shall be set to 1 less than the number of subframes present within the current frame. That is, **L1B_num_subframes**=0 shall indicate that 1 subframe is present within the current frame, **L1B_num_subframes**=1 shall indicate that two subframes are present within the current frame, and so on.

### 9.2.2 L1-Basic Parameters for L1-Detail

The following parameters provide information required to decode the remainder of the Preamble, that is, L1-Detail.

**L1B_preamble_num_symbols** – This field shall be set to one less than the total number of Preamble OFDM symbols. Example: When there is just one Preamble symbol, **L1B_preamble_num_symbols** would be set equal to 0.

**L1B_preamble_reduced_carriers** – This field shall indicate the number of control units of carriers by which the maximum number of carriers for the FFT size used for the Preamble is reduced. This carrier reduction shall apply to all of the Preamble symbols of the current frame with the exception of the first Preamble symbol. See Section 7.2.6.3 for details. When there is only one Preamble symbol, the value of this field shall be zero.

**L1B_L1_Detail_content_tag** – This field shall be incremented by 1 whenever the L1-Detail contents of the current frame have been modified as compared to the L1-Detail contents of the previous frame with a bootstrap of the same major and minor version as the current frame. The following signaling fields are excluded from determination of when to increment **L1B_L1_Detail_content_tag**: **L1D_time_sec**, **L1D_time_msec**, **L1D_time_usec**, **L1D_time_nsec** (including the presence or absence of any of these listed time fields) **L1D_plp_lls_flag**, **L1D_plp_fec_block_start**, **L1D_plp_CTI_fec_block_start**, and **L1D_plp_CTI_start_row**. The initial value of **L1B_L1_Detail_content_tag** shall be 0. When **L1B_L1_Detail_content_tag** is incremented after reaching the maximum value, it shall wrap, and the next transmitted value shall be 0.

**L1B_L1_Detail_size_bytes** – This field shall indicate the size (in bytes) of the L1-Detail information. The indicated number of L1-Detail information bytes shall not include any additional parity bits that are included in the current frame for the next frame's L1-Detail. The minimum value of this field shall be 25 bytes.

**L1B_L1_Detail_fec_type** – This field shall indicate the FEC type for L1-Detail information protection as given in Table 9.6. The details of the FEC type are described in Section 6.5.2.1.

**Table 9.6** Signaling Format for **L1B_L1_Detail_fec_type**

| Value | FEC Type |
|---|---|
| 000 | Mode 1 |
| 001 | Mode 2 |
| 010 | Mode 3 |
| 011 | Mode 4 |
| 100 | Mode 5 |
| 101 | Mode 6 |
| 110 | Mode 7 |
| 111 | Reserved |

**L1B_L1_Detail_additional_parity_mode** – This field shall indicate the Additional Parity Mode (defined in Section 6.5.3.2) which gives the ratio ($K$) of the number of additional parity bits for the next frame's L1-Detail that are carried in the current frame to half of the number of coded bits for the next frame's L1-Detail signaling. (Here, the next frame shall be considered to be the next frame whose bootstrap has the same major and minor version as the current frame.) The value of the field shall be given as shown in Table 9.7.

**Table 9.7** Signaling Format for **L1B_additional_parity_mode**

| Value | Additional Parity Mode |
|---|---|
| 00 | K = 0 (No additional parity used) |
| 01 | K = 1 |
| 10 | K = 2 |
| 11 | Reserved for future use |

**L1B_L1_Detail_total_cells** – This field shall indicate the total size (specified in OFDM cells) of the combined coded and modulated L1-Detail signaling for the current frame and the modulated additional parity bits for L1-Detail signaling of the next frame.

### 9.2.3 L1-Basic Parameters for First Subframe

The parameters of the first subframe of the current frame are signaled within L1-Basic to facilitate the immediate initial OFDM processing of this first subframe at a receiver without needing to wait until L1-Detail is decoded.

**L1B_first_sub_mimo** – This field shall indicate whether MIMO (see Annex L) is used for the first subframe of the current frame. A value of 1 shall indicate that MIMO is used, and a value of 0 shall indicate that MIMO is not used.

**L1B_first_sub_miso** – This field shall indicate the MISO (see Section 8.2) option used for the first subframe of the current frame as given in Table 9.9.

**L1B_first_sub_fft_size** – This field shall indicate the FFT size associated with the first subframe of the current frame as given in Table 9.10. Note that the FFT size of a frame's Preamble and the FFT size of the same frame's first subframe are the same, as specified in Section 7.2.2.1.

**L1B_first_sub_reduced_carriers** – This field shall indicate the number of control units of carriers by which the maximum number of carriers for the FFT size used for the first subframe of the current frame is reduced. This carrier reduction shall apply to all of the symbols of the first subframe of the current frame (see Section 7.2.3 for details).

**L1B_first_sub_guard_interval** – This field shall indicate the guard interval length used for the OFDM symbols of the first subframe of the current frame as given in Table 9.11. Guard interval lengths (e.g. 192 samples for GI1_192) shall be as defined in Table 8.9. Note that the signaled guard interval length for the first subframe of a frame is the same as the guard interval length indicated for that same frame's Preamble, as specified in Section 7.2.2.1.

**L1B_first_sub_num_ofdm_symbols** – This field shall be set equal to one less than the total number of data payload OFDM symbols, including any subframe boundary symbol(s), present within the first subframe of the current frame. The number of data payload OFDM symbols in a subframe is greater than or equal to $4 \times D_Y$ where $D_Y$ is taken from the scattered pilot pattern that is configured for the subframe (see Section 7.2.4.2). OFDM symbols containing Preamble signaling shall not be included within this count, although OFDM symbols containing Preamble signaling may also carry portions of PLPs associated with the first subframe of a frame if data cells are available on those OFDM symbols.

**L1B_first_sub_scattered_pilot_pattern** – This field shall indicate the scattered pilot pattern used for the first subframe of the current frame as given in Table 9.12 for SISO, and as given in Table 9.13 for MIMO. SP pattern values (e.g. SP3_2, MIMO3_2) shall be as defined in Table 8.2 (SISO) and Table L.9.2 (MIMO).

**L1B_first_sub_scattered_pilot_boost** – The value of this field combined with the scattered pilot pattern shall represent the power of the scattered pilots (in dB) used for the first subframe of the current frame. The exact power values (used to calculate the amplitude) shall be as defined in Table 9.14. Equivalent but approximate amplitudes (after conversion from dB to linear) of the scattered pilots are listed in Table 9.15. The values of 101, 110 and 111 shall be reserved for future use.

**L1B_first_sub_sbs_first** – This field shall indicate whether or not the first symbol of the first subframe of the current frame is a subframe boundary symbol. **L1B_first_sub_sbs_first**=0 shall indicate that the first symbol of the first subframe of the current frame is not a subframe boundary symbol. **L1B_first_sub_sbs_first**=1 shall indicate that the first symbol of the first subframe of the current frame is a subframe boundary symbol.

**L1B_first_sub_sbs_last** – This field shall indicate whether or not the last symbol of the first subframe of the current frame is a subframe boundary symbol. **L1B_first_sub_sbs_last**=0 shall indicate that the last symbol of the first subframe of the current frame is not a subframe boundary symbol. **L1B_first_sub_sbs_last**=1 shall indicate that the last symbol of the first subframe of the current frame is a subframe boundary symbol.

### 9.2.4 L1-Basic Miscellaneous Parameters

The remaining miscellaneous parameters in L1-Basic are as follows.

**L1B_reserved** – This field shall contain reserved bits as required to pad L1-Basic out to the total length. It is envisaged that any new signaling fields defined for a newer version of the L1-Basic signaling structure would occupy a portion of these reserved bits to maintain backward-compatibility for legacy receivers. Receivers are expected to ignore the contents of **L1B_reserved**.

**L1B_crc** – This field shall contain the CRC value as computed according to Section 6.1.2.2 over the contents of L1-Basic excluding the **L1B_crc** field.

## 9.3 Syntax and Semantics for L1-Detail Data

The syntax and field semantics of the L1-Detail signaling fields shall be as defined in Table 9.8 and the following subsections. The names of signaling fields in L1-Detail are always prefixed with '**L1D_**'.

**Table 9.8** L1-Detail Signaling Fields and Syntax

| Syntax | No. of Bits | Format |
|---|---|---|
| L1_Detail_signaling() { | | |
| **L1D_version** | 4 | uimsbf |
| **L1D_num_rf** | 3 | uimsbf |
| for (**L1D_rf_id=1 .. L1D_num_rf**) { | | |
| **L1D_bonded_bsid** | 16 | uimsbf |
| **reserved** | 3 | bslbf |
| } | | |
| if (**L1B_time_info_flag** != 00) { | | |
| **L1D_time_sec** | 32 | uimsbf |
| **L1D_time_msec** | 10 | uimsbf |
| if (**L1B_time_info_flag** != 01) { | | |
| **L1D_time_usec** | 10 | uimsbf |
| if (**L1B_time_info_flag** != 10) { | | |
| **L1D_time_nsec** | 10 | uimsbf |
| } | | |
| } | | |
| } | | |
| | | |
| for (**i=0 .. L1B_num_subframes**) { | | |
| if (i > 0) { | | |
| **L1D_mimo** | 1 | uimsbf |
| **L1D_miso** | 2 | uimsbf |
| **L1D_fft_size** | 2 | uimsbf |
| **L1D_reduced_carriers** | 3 | uimsbf |
| **L1D_guard_interval** | 4 | uimsbf |
| **L1D_num_ofdm_symbols** | 11 | uimsbf |
| **L1D_scattered_pilot_pattern** | 5 | uimsbf |
| **L1D_scattered_pilot_boost** | 3 | uimsbf |
| **L1D_sbs_first** | 1 | uimsbf |
| **L1D_sbs_last** | 1 | uimsbf |
| } | | |
| if (**L1B_num_subframes**>0) { | | |
| **L1D_subframe_multiplex** | 1 | uimsbf |
| } | | |
| **L1D_frequency_interleaver** | 1 | uimsbf |
| if (((i=0)&&(**L1B_first_sub_sbs_first** \|\| **L1B_first_sub_sbs_last**)) \|\| | | |
| ((i>0)&&(**L1D_sbs_first** \| **L1D_sbs_last**))) { | | |
| **L1D_sbs_null_cells** | 13 | uimsbf |
| } | | |
| **L1D_num_plp** | 6 | uimsbf |

| Syntax | No. of Bits | Format |
|---|---|---|
| for (j=0 .. **L1D_num_plp**) { | | |
| **L1D_plp_id** | 6 | uimsbf |
| **L1D_plp_lls_flag** | 1 | uimsbf |
| **L1D_plp_layer** | 2 | uimsbf |
| **L1D_plp_start** | 24 | uimsbf |
| **L1D_plp_size** | 24 | uimsbf |
| **L1D_plp_scrambler_type** | 2 | uimsbf |
| **L1D_plp_fec_type** | 4 | uimsbf |
| if (**L1D_plp_fec_type**∈{0,1,2,3,4,5}) { | | |
| **L1D_plp_mod** | 4 | uimsbf |
| **L1D_plp_cod** | 4 | uimsbf |
| } | | |
| **L1D_plp_TI_mode** | 2 | uimsbf |
| if (**L1D_plp_TI_mode**=00) { | | |
| **L1D_plp_fec_block_start** | 15 | uimsbf |
| } else if (**L1D_plp_TI_mode**=01) { | | |
| **L1D_plp_CTI_fec_block_start** | 22 | uimsbf |
| } | | |
| if (**L1D_num_rf**>0) { | | |
| **L1D_plp_num_channel_bonded** | 3 | uimsbf |
| if (**L1D_plp_num_channel_bonded**>0) { | | |
| **L1D_plp_channel_bonding_format** | 2 | uimsbf |
| for (k=0..**L1D_plp_num_channel_bonded**){ | | |
| **L1D_plp_bonded_rf_id** | 3 | uimsbf |
| } | | |
| } | | |
| } | | |
| if (i=0 && **L1B_first_sub_mimo**=1) \|\| (i >0 && **L1D_mimo**=1) { | | |
| **L1D_plp_mimo_stream_combining** | 1 | uimsbf |
| **L1D_plp_mimo_IQ_interleaving** | 1 | uimsbf |
| **L1D_plp_mimo_PH** | 1 | uimsbf |
| } | | |
| if (**L1D_plp_layer**=0) { | | |
| **L1D_plp_type** | 1 | uimsbf |
| if (**L1D_plp_type**=1) { | | |
| **L1D_plp_num_subslices** | 14 | uimsbf |
| **L1D_plp_subslice_interval** | 24 | uimsbf |
| } | | |
| if (((**L1D_plp_TI_mode**=01) \|\| | | |
| (**L1D_plp_TI_mode**=10))&&(**L1D_plp_mod**=0000)) { | | |
| **L1D_plp_TI_extended_interleaving** | 1 | uimsbf |
| } | | |
| if (**L1D_plp_TI_mode**=01) { | | |
| **L1D_plp_CTI_depth** | 3 | uimsbf |
| **L1D_plp_CTI_start_row** | 11 | uimsbf |
| }else if (**L1D_plp_TI_mode**=10) { | | |
| **L1D_plp_HTI_inter_subframe** | 1 | uimsbf |

| Syntax | No. of Bits | Format |
|---|---|---|
| **L1D_plp_HTI_num_ti_blocks** | 4 | uimsbf |
| **L1D_plp_HTI_num_fec_blocks_max** | 12 | uimsbf |
| if (**L1D_plp_HTI_inter_subframe**=0) { | | |
| **L1D_plp_HTI_num_fec_blocks** | 12 | uimsbf |
| }else { | | |
| for (k=0..**L1D_plp_HTI_num_ti_blocks**) { | | |
| **L1D_plp_HTI_num_fec_blocks** | 12 | uimsbf |
| } | | |
| } | | |
| **L1D_plp_HTI_cell_interleaver** | 1 | uimsbf |
| } | | |
| }else { | | |
| **L1D_plp_ldm_injection_level** | 5 | uimsbf |
| } | | |
| } | | |
| } | | |
| **L1D_bsid** | 16 | uimsbf |
| **L1D_reserved** | as needed | uimsbf |
| **L1D_crc** | 32 | uimsbf |
| } | | |

### 9.3.1 L1-Detail Miscellaneous Parameters

The following miscellaneous parameters are included in L1-Detail.

**L1D_version** – This field shall indicate the version of the L1-Detail signaling structure that is used for the current frame. For the current version of the specification **L1D_version** shall be set to 1. It is envisaged that when new L1-Detail signaling fields are introduced into an updated L1-Detail signaling structure in such a manner that the presence or absence of at least one of those new L1-Detail signaling fields cannot be otherwise deduced, **L1D_version** would be incremented by 1. New L1-Detail signaling fields that are introduced into an L1-Detail signaling structure corresponding to a particular **L1D_version** are added in such a manner that they do not interfere with the parsing of L1-Detail signaling fields by receivers that have been provisioned only up to an earlier **L1D_version**. New L1-Detail signaling fields can be added immediately before **L1D_reserved** such that these new L1-Detail signaling fields immediately follow all of the previously existing L1-Detail signaling fields with the exception of **L1D_reserved** and **L1D_crc**. With this approach, a parser built to a previous version of this standard would consider any new L1-Detail signaling fields to be part of **L1D_reserved**. The length of **L1D_reserved** for a particular frame is calculated by subtracting the aggregate lengths of all known and included L1-Detail signaling fields from **L1B_L1_Detail_size_bytes**, and thus a parser built to a previous version of this standard would be able to parse the known portions of L1-Detail successfully without requiring knowledge of the structure or contents of any new fields added to what that parser would perceive as **L1D_reserved**.

**L1D_time_sec** – This field is the seconds portion of the precise time at which the first sample of the first symbol of the most recently received bootstrap was transmitted, shown as the Time Information Position in Figure 9.1. **L1D_time_sec** shall contain the 32 least significant bits of the number of seconds elapsed between the PTP epoch (see IEEE 1588 [6], Section 7.2.2) and the precise time at which the first sample of the first symbol of the most recently received

bootstrap was transmitted. (Note that this calculation is performed before leap seconds are subtracted.) For example, if the precise time was 17:30:48 UTC (i.e., 17:31:24 TAI) on the 12th February 2016 there would have been exactly 1455298284 seconds elapsed since the PTP epoch (which is 1st January 1970 00:00:00 TAI) and the value transmitted in this field would be 0x56BE16EC. The difference between TAI and UTC seconds is signaled in A/331 **SystemTime@currentUtcOffset** (see A/331 [5], Section 6.4). The time value shall be transmitted at least once in every 5 second interval.

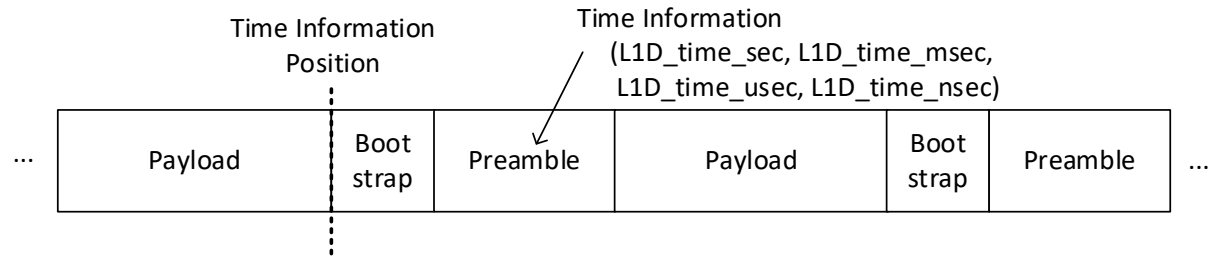


**Figure 9.1** Illustration of the time information position and the time information being transmitted in the Preamble.

**L1D_time_msec** – This field shall indicate the milliseconds component of the time information specified under **L1D_time_sec**. For example, if the portion of the time information less than one second is 0.123456789 this field shall be 123.

**L1D_time_usec** – This field shall indicate the microseconds component of the time information specified under **L1D_time_sec**. For example, if the portion of the time information less than one second is 0.123456789 this field shall be 456.

**L1D_time_nsec** – This field shall indicate the nanoseconds component of the time information specified under **L1D_time_sec**. For example, if the portion of the time information less than one second is 0.123456789 this field shall be 789.

**L1D_reserved** – This field shall contain reserved bits as needed to pad L1-Detail out to the total bit length indicated by **L1B_L1_Detail_size_bytes**. It is expected that one primary use of **L1D_reserved** on the transmitter side will be to ensure byte alignment of the total length of L1-Detail by including from 0 to 7 padding bits as required. Future versions of the L1-Detail signaling structure may add new signaling fields, which would be seen as part of the **L1D_reserved** field by legacy receivers. Receivers are therefore expected not to make any assumptions about the expected contents and/or length of **L1D_reserved**.

**L1D_crc** – This field shall contain the CRC value as computed in Section 6.1.2.2 over the contents of L1-Detail excluding the **L1D_crc** field.

### 9.3.2 L1-Detail Channel Bonding Parameters (Frame)

The following L1-Detail signaling fields are related to channel bonding.

**L1D_num_rf** – This field shall indicate the number of frequencies involved in channel bonding, not including the frequency of the present channel. For the current version of the specification **L1D_num_rf** shall have a maximum value of 1 (i.e. bonding of the current channel with one other channel). **L1D_num_rf**=0 shall indicate that channel bonding is not used for the current frame.

**L1D_rf_id** – This implicitly defined field shall specify the IDs of the other RF channels involved in channel bonding. The current RF channel shall be assigned an implicit **L1D_rf_id** of 0. The first

RF channel in the list shall be assigned an implicit **L1D_rf_id** of 1, and so on. For the current version of the specification **L1D_rf_id**, if defined, shall have a maximum value of 1.

**L1D_bonded_bsid** – This field shall indicate the BSID of a separate RF channel that is channel bonded with the current RF channel, and that is associated with the implicit ID of **L1D_rf_id**. The BSID of the current channel is **L1D_bsid.**

**L1D_bsid** – This field shall indicate the BSID of the current channel. The value of **L1D_bsid** shall be unique on a regional level (for example, North America). An administrative or regulatory authority may play a role in assuring the uniqueness of this value. This field was defined starting with **L1D_version** = 1.

### 9.3.3 L1-Detail Subframe Parameters

L1-Detail parameters related to subframe configuration are as follows.

**L1D_mimo** – This flag shall indicate whether MIMO (see Annex L) is used for the current subframe. A value of 1 shall indicate that MIMO is used, and a value of 0 shall indicate that MIMO is not used.

**L1D_miso** – This field shall indicate the MISO (see Section 8.2) option used for the current subframe as given in Table 9.9.

**Table 9.9** Signaling Format for **L1D_miso** and **L1B_first_sub_miso**

| Value | MISO option |
|---|---|
| 00 | No MISO |
| 01 | MISO with 64 coefficients |
| 10 | MISO with 256 coefficients |
| 11 | Reserved |

**L1D_fft_size** – This field shall indicate the FFT size associated with the current subframe as given in Table 9.10.

**Table 9.10** Signaling Format for **L1D_fft_size** and **L1B_first_sub_fft_size**

| Value | FFT Size |
|---|---|
| 00 | 8K |
| 01 | 16K |
| 10 | 32K |
| 11 | Reserved |

**L1D_reduced_carriers** – This field shall indicate the number of control units of carriers by which the maximum number of carriers for the FFT size used for the current subframe of the current frame is reduced. This carrier reduction shall apply to all of the symbols of the current subframe of the current frame (see Section 7.2.3 for details). The values of 5, 6, and 7 for **L1D_reduced_carriers** shall be reserved.

**L1D_guard_interval** – This field shall indicate the guard interval length used for the OFDM symbols of the current subframe as given in Table 9.11. Guard interval values from Table 9.11 (e.g. GI1_192) shall be as defined in Table 8.9.

**Table 9.11** Signaling Format for **L1D_guard_interval** and **L1B_first_sub_guard_interval**

| Value | Guard Interval | Value | Guard Interval |
|---|---|---|---|
| **0000** | Reserved | **1000** | GI8_2432 |
| **0001** | GI1_192 | **1001** | GI9_3072 |
| **0010** | GI2_384 | **1010** | GI10_3648 |
| **0011** | GI3_512 | **1011** | GI11_4096 |
| **0100** | GI4_768 | **1100** | GI12_4864 |
| **0101** | GI5_1024 | **1101** | Reserved |
| **0110** | GI6_1536 | **1110** | Reserved |
| **0111** | GI7_2048 | **1111** | Reserved |

**L1D_num_ofdm_symbols** – This field shall be set equal to one less than the total number of data payload OFDM symbols, including any subframe-boundary symbol(s), present within the current subframe. The number of data payload OFDM symbols in a subframe is greater than or equal to $4 \times D_Y$ where $D_Y$ is taken from the scattered pilot pattern that is configured for the subframe (see Section 7.2.4.2). OFDM symbols containing Preamble signaling shall not be included within this count.

**L1D_scattered_pilot_pattern** – This field shall indicate the scattered pilot pattern used for the current subframe as given in Table 9.12 for SISO, and as given in Table 9.13 for MIMO. SP pattern values (e.g. SP3_2, MP3_2) shall be as defined in Table 8.2 (SISO) and Table L.9.2 (MIMO). Note that MP24_2, MP24_4, MP32_2, and MP32_4 are invalid pilot patterns when Walsh-Hadamard pilot encoding is configured with MIMO operation (see Section L.9.2).

**Table 9.12** Signaling Format for **L1D_scattered_pilot_pattern** and **L1B_first_sub_scattered_pilot_pattern** for SISO

| Value | SP pattern | Value | SP pattern | Value | SP pattern |
|---|---|---|---|---|---|
| **00000** | SP3_2 | **01000** | SP12_2 | **10000** | Reserved |
| **00001** | SP3_4 | **01001** | SP12_4 | **…** | … |
| **00010** | SP4_2 | **01010** | SP16_2 | **…** | … |
| **00011** | SP4_4 | **01011** | SP16_4 | **…** | … |
| **00100** | SP6_2 | **01100** | SP24_2 | **…** | … |
| **00101** | SP6_4 | **01101** | SP24_4 | **…** | … |
| **00110** | SP8_2 | **01110** | SP32_2 | **…** | … |
| **00111** | SP8_4 | **01111** | SP32_4 | **11111** | Reserved |

**Table 9.13** Signaling Format for **L1D_scattered_pilot_pattern** and **L1B_first_sub_scattered_pilot_pattern** for MIMO

| Value | SP pattern | Value | SP pattern | Value | SP pattern |
|---|---|---|---|---|---|
| **00000** | MP3_2 | **01000** | MP12_2 | **10000** | Reserved |
| **00001** | MP3_4 | **01001** | MP12_4 | **…** | … |
| **00010** | MP4_2 | **01010** | MP16_2 | **…** | … |
| **00011** | MP4_4 | **01011** | MP16_4 | **…** | … |
| **00100** | MP6_2 | **01100** | MP24_2 | **…** | … |
| **00101** | MP6_4 | **01101** | MP24_4 | **…** | … |
| **00110** | MP8_2 | **01110** | MP32_2 | **…** | … |
| **00111** | MP8_4 | **01111** | MP32_4 | **11111** | Reserved |

**L1D_scattered_pilot_boost** – The value of this field combined with the scattered pilot pattern shall represent the power of the scattered pilots (in dB) used for the current subframe. The exact power values (used to calculate the amplitude) shall be as defined in Table 9.14. Equivalent but approximate amplitudes (after conversion from dB to linear) of the scattered pilots are listed in Table 9.15. The values of 101, 110 and 111 shall be reserved for future use (*RFU*).

**Table 9.14** Signaling Format for **L1D_scattered_pilot_boost** (power in dB)

| **Pilot Pattern (SISO / MIMO)** | **L1D_scattered_pilot_boost** | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | **000** | **001** | **010** | **011** | **100** | **101** | **110** | **111** |
| SP3_2 / MP3_2 | 0.00 | 0.00 | 1.40 | 2.20 | 2.90 | *RFU* | *RFU* | *RFU* |
| SP3_4 / MP3_4 | 0.00 | 1.40 | 2.90 | 3.80 | 4.40 | *RFU* | *RFU* | *RFU* |
| SP4_2 / MP4_2 | 0.00 | 0.60 | 2.10 | 3.00 | 3.60 | *RFU* | *RFU* | *RFU* |
| SP4_4 / MP4_4 | 0.00 | 2.10 | 3.60 | 4.40 | 5.10 | *RFU* | *RFU* | *RFU* |
| SP6_2 / MP6_2 | 0.00 | 1.60 | 3.10 | 4.00 | 4.60 | *RFU* | *RFU* | *RFU* |
| SP6_4 / MP6_4 | 0.00 | 3.00 | 4.50 | 5.40 | 6.00 | *RFU* | *RFU* | *RFU* |
| SP8_2 / MP8_2 | 0.00 | 2.20 | 3.80 | 4.60 | 5.30 | *RFU* | *RFU* | *RFU* |
| SP8_4 / MP8_4 | 0.00 | 3.60 | 5.10 | 6.00 | 6.60 | *RFU* | *RFU* | *RFU* |
| SP12_2 / MP12_2 | 0.00 | 3.20 | 4.70 | 5.60 | 6.20 | *RFU* | *RFU* | *RFU* |
| SP12_4 / MP12_4 | 0.00 | 4.50 | 6.00 | 6.90 | 7.50 | *RFU* | *RFU* | *RFU* |
| SP16_2 / MP16_2 | 0.00 | 3.80 | 5.30 | 6.20 | 6.80 | *RFU* | *RFU* | *RFU* |
| SP16_4 / MP16_4 | 0.00 | 5.20 | 6.70 | 7.60 | 8.20 | *RFU* | *RFU* | *RFU* |
| SP24_2 / MP24_2 | 0.00 | 4.70 | 6.20 | 7.10 | 7.70 | *RFU* | *RFU* | *RFU* |
| SP24_4 / MP24_4 | 0.00 | 6.10 | 7.60 | 8.50 | 9.10 | *RFU* | *RFU* | *RFU* |
| SP32_2 / MP32_2 | 0.00 | 5.40 | 6.90 | 7.70 | 8.40 | *RFU* | *RFU* | *RFU* |
| SP32_4 / MP32_4 | 0.00 | 6.70 | 8.20 | 9.10 | 9.70 | *RFU* | *RFU* | *RFU* |

**Table 9.15** Equivalent Signaling Format for **L1D_scattered_pilot_boost** (amplitude)

| **Pilot Pattern (SISO / MIMO)** | **L1D_scattered_pilot_boost** | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | **000** | **001** | **010** | **011** | **100** | **101** | **110** | **111** |
| SP3_2 / MP3_2 | *1.000* | *1.000* | *1.175* | *1.288* | *1.396* | *RFU* | *RFU* | *RFU* |
| SP3_4 / MP3_4 | *1.000* | *1.175* | *1.396* | *1.549* | *1.660* | *RFU* | *RFU* | *RFU* |
| SP4_2 / MP4_2 | *1.000* | *1.072* | *1.274* | *1.413* | *1.514* | *RFU* | *RFU* | *RFU* |
| SP4_4 / MP4_4 | *1.000* | *1.274* | *1.514* | *1.660* | *1.799* | *RFU* | *RFU* | *RFU* |
| SP6_2 / MP6_2 | *1.000* | *1.202* | *1.429* | *1.585* | *1.698* | *RFU* | *RFU* | *RFU* |
| SP6_4 / MP6_4 | *1.000* | *1.413* | *1.679* | *1.862* | *1.995* | *RFU* | *RFU* | *RFU* |
| SP8_2 / MP8_2 | *1.000* | *1.288* | *1.549* | *1.698* | *1.841* | *RFU* | *RFU* | *RFU* |
| SP8_4 / MP8_4 | *1.000* | *1.514* | *1.799* | *1.995* | *2.138* | *RFU* | *RFU* | *RFU* |
| SP12_2 / MP12_2 | *1.000* | *1.445* | *1.718* | *1.905* | *2.042* | *RFU* | *RFU* | *RFU* |
| SP12_4 / MP12_4 | *1.000* | *1.679* | *1.995* | *2.213* | *2.371* | *RFU* | *RFU* | *RFU* |
| SP16_2 / MP16_2 | *1.000* | *1.549* | *1.841* | *2.042* | *2.188* | *RFU* | *RFU* | *RFU* |
| SP16_4 / MP16_4 | *1.000* | *1.820* | *2.163* | *2.399* | *2.570* | *RFU* | *RFU* | *RFU* |
| SP24_2 / MP24_2 | *1.000* | *1.718* | *2.042* | *2.265* | *2.427* | *RFU* | *RFU* | *RFU* |
| SP24_4 / MP24_4 | *1.000* | *2.018* | *2.399* | *2.661* | *2.851* | *RFU* | *RFU* | *RFU* |
| SP32_2 / MP32_2 | *1.000* | *1.862* | *2.213* | *2.427* | *2.630* | *RFU* | *RFU* | *RFU* |
| SP32_4 / MP32_4 | *1.000* | *2.163* | *2.570* | *2.851* | *3.055* | *RFU* | *RFU* | *RFU* |

**L1D_sbs_first** – This flag shall indicate whether or not the first symbol of the current subframe is a subframe boundary symbol. **L1D_sbs_first**=0 shall indicate that the first symbol of the subframe is not a subframe boundary symbol. **L1D_sbs_first**=1 shall indicate that the first symbol of the subframe is a subframe boundary symbol.

**L1D_sbs_last** – This flag shall indicate whether or not the last symbol of the current subframe is a subframe boundary symbol. **L1D_sbs_last**=0 shall indicate that the last symbol of the subframe is not a subframe boundary symbol. **L1D_sbs_last**=1 shall indicate that the last symbol of the subframe is a subframe boundary symbol.

**L1D_subframe_multiplex** – This field shall indicate whether the current subframe is time-division multiplexed / concatenated in time (**L1D_subframe_multiplex**=0) with adjacent subframes. **L1D_subframe_multiplex**=1 shall be reserved for future use.

**L1D_frequency_interleaver** – This flag shall indicate whether the frequency interleaver is enabled or bypassed for the current subframe. **L1D_frequency_interleaver**=1 shall indicate that the frequency interleaver is enabled, **L1D_frequency_interleaver**=0 shall indicate that the frequency interleaver is bypassed and not used.

**L1D_sbs_null_cells** – This field shall indicate the number of null cells in the subframe boundary symbol(s) of the current subframe. When there are no subframe boundary symbols in the current subframe, this field shall not be transmitted.

### 9.3.4 L1-Detail PLP Parameters

The following L1-Detail signaling fields are related to PLP characteristics.

**L1D_num_plp** – This field shall be set to 1 less than the total number of PLPs used within the current subframe.

**L1D_plp_id** – This field shall be set equal to the ID of the current PLP, with a range from 0 to 63, inclusive. This field shall identify a PLP uniquely within each RF channel. For channel-bonded systems, the combination of **L1D_rf_id** and this field can be used to create a unique identifier for each PLP within the bonded system.

**L1D_plp_lls_flag** – This field shall indicate whether the current PLP carries LLS information. **L1D_plp_lls_flag**=0 shall indicate that the current PLP does not carry LLS information (in any frame), while **L1D_plp_lls_flag**=1 shall indicate that the current PLP does carry LLS information (although not necessarily in the current frame or subframe). The purpose of this flag is to allow receivers to quickly locate upper layer signaling information. Receivers can use **L1B_lls_flag** to determine whether or not at least one PLP in the current frame actually contains LLS information in the current frame. Note, however, that certain broadcast configurations can result in multiple PLPs carrying LLS information within a single RF channel, and hence **L1B_lls_flag** being set does not necessarily indicate that the LLS-bearing PLP of interest to a particular receiver contains LLS information in the current frame.

**L1D_plp_size** – This field shall be set equal to the number of data cells allocated to the current PLP within the current subframe. **L1D_plp_size** shall be greater than zero.

**L1D_plp_scrambler_type** – This field shall indicate the choice of scrambler type for the PLP as given in Table 9.16.

**Table 9.16** Signaling Format for **L1D_plp_scrambler_type**

| Value | Description |
|---|---|
| 00 | Scrambler defined in Section 5.2.3 |
| 01 | Reserved for future use |
| 10 | Reserved for future use |
| 11 | Reserved for future use |

**L1D_plp_fec_type** – This field shall indicate the Forward Error Correction (FEC) method used for encoding the current PLP. The correspondence between a signaled value of **L1D_plp_fec_type** and a particular FEC method shall be as given in Table 9.17. Here, 16K LDPC refers to the LDPC FEC coding that generates a set of 16200 coded bits per code block, and 64K LDPC refers to the LDPC FEC coding that generates a set of 64800 coded bits per code block.

**Table 9.17** Signaling Format for **L1D_plp_fec_type**

| Value | Forward Error Correction Method |
|---|---|
| 0000 | BCH + 16K LDPC |
| 0001 | BCH + 64K LDPC |
| 0010 | CRC + 16K LDPC |
| 0011 | CRC + 64K LDPC |
| 0100 | 16K LDPC only |
| 0101 | 64K LDPC only |
| 0110 - 1111 | Reserved for future use |

**L1D_plp_mod** – This field shall indicate the modulation used for the current PLP as given in Table 9.18 for SISO, and as given in Table 9.19 for MIMO. Modulations of 1024QAM-NUC and 4096QAM-NUC shall only be indicated when **L1D_plp_fec_type** for the same PLP indicates a 64K LDPC.

**Table 9.18** Signaling Format for **L1D_plp_mod** for SISO

| Value | Modulation |
|---|---|
| 0000 | QPSK |
| 0001 | 16QAM-NUC |
| 0010 | 64QAM-NUC |
| 0011 | 256QAM-NUC |
| 0100 | 1024QAM-NUC |
| 0101 | 4096QAM-NUC |
| 0110-1111 | Reserved |

**Table 9.19** Signaling Format for **L1D_plp_mod** for MIMO

| Value | Bits per Cell Unit | MIMO Modulation | |
|---|---|---|---|
| 0000 | 4 | Tx1 | QPSK |
| | | Tx2 | QPSK |
| 0001 | 8 | Tx1 | 16QAM-NUC |
| | | Tx2 | 16QAM-NUC |
| 0010 | 12 | Tx1 | 64QAM-NUC |
| | | Tx2 | 64QAM-NUC |

| | | | |
|---|---|---|---|
| 0011 | 16 | Tx1 | 256QAM-NUC |
| | | Tx2 | 256QAM-NUC |
| 0100 | 20 | Tx1 | 1024QAM-NUC |
| | | Tx2 | 1024QAM-NUC |
| 0101 | 24 | Tx1 | 4096QAM-NUC |
| | | Tx2 | 4096QAM-NUC |
| 0110 to 1111 | Reserved | Reserved | |

**L1D_plp_cod** – This field shall indicate the code rate used for the current PLP as shown in Table 9.18.

**Table 9.20** Signaling Format for **L1D_plp_cod**

| Value | Code Rate |
|---|---|
| 0000 | 2/15 |
| 0001 | 3/15 |
| 0010 | 4/15 |
| 0011 | 5/15 |
| 0100 | 6/15 |
| 0101 | 7/15 |
| 0110 | 8/15 |
| 0111 | 9/15 |
| 1000 | 10/15 |
| 1001 | 11/15 |
| 1010 | 12/15 |
| 1011 | 13/15 |
| 1100-1111 | Reserved |

**L1D_plp_TI_mode** – This field shall indicate the time interleaving mode for the PLP as given in Table 9.21.

**Table 9.21** Signaling Format for **L1D_plp_TI_mode**

| Value | Time interleaving mode |
|---|---|
| 00 | No time interleaving mode (neither CTI nor HTI) |
| 01 | Convolutional time interleaving (CTI) mode |
| 10 | Hybrid time interleaving (HTI) mode |
| 11 | Reserved for future use |

**L1D_plp_fec_block_start** – This field shall indicate the start position of the first complete FEC Block that begins within the current PLP during the current subframe. **L1D_plp_fec_block_start** for a PLP shall indicate the relative position, within and relative to the start of that PLP's data cells for the current subframe, of the first cell of the first complete FEC Block of the PLP beginning within the current subframe. **L1D_plp_fec_block_start** shall be determined prior to cell multiplexing. When no FEC Block begins within the current PLP during the current subframe, **L1D_plp_fec_block_start** shall be set to its maximum possible value (i.e. all bits of **L1D_plp_fec_block_start** shall be set to 1s). When LDM is used, **L1D_plp_fec_block_start** shall be signaled for both Core and Enhanced PLPs since the start positions of the first complete FEC Block of Core and Enhanced PLPs that have been layered division multiplexed together, in

general, are different. **L1D_plp_fec_block_start** shall be signalled only when **L1D_plp_TI_mode**=00 (i.e. when no time interleaving mode is configured).

### 9.3.5 L1-Detail LDM Parameters

The following L1-Detail signaling fields are related to Layered Division Multiplexing (LDM).

**L1D_plp_layer** – This field shall be set equal to the layer index of the current PLP. **L1D_plp_layer**=0 shall correspond to the Core Layer, while **L1D_plp_layer**>0 shall correspond to an Enhanced Layer. For the current version of the specification, **L1D_plp_layer** shall only be set to values of 0 or 1.

**L1D_plp_ldm_injection_level** – This field shall indicate the Enhanced PLP's injection level relative to the Core PLP. The correspondence between a signaled value of **L1D_plp_ldm_injection_level** and a particular injection level shall be as given in Table 9.22. Injection levels are defined in Table 6.15. This field shall only be included when the index of the current layer is greater than 0 (i.e. when **L1D_plp_layer** > 0).

**Table 9.22** Signaling Format for **L1D_plp_ldm_injection_level**

| Value | Injection level [dB] | Value | Injection level [dB] |
|---|---|---|---|
| **00000** | 0.0 | **10000** | 11.0 |
| **00001** | 0.5 | **10001** | 12.0 |
| **00010** | 1.0 | **10010** | 13.0 |
| **00011** | 1.5 | **10011** | 14.0 |
| **00100** | 2.0 | **10100** | 15.0 |
| **00101** | 2.5 | **10101** | 16.0 |
| **00110** | 3.0 | **10110** | 17.0 |
| **00111** | 3.5 | **10111** | 18.0 |
| **01000** | 4.0 | **11000** | 19.0 |
| **01001** | 4.5 | **11001** | 20.0 |
| **01010** | 5.0 | **11010** | 21.0 |
| **01011** | 6.0 | **11011** | 22.0 |
| **01100** | 7.0 | **11100** | 23.0 |
| **01101** | 8.0 | **11101** | 24.0 |
| **01110** | 9.0 | **11110** | 25.0 |
| **01111** | 10.0 | **11111** | Reserved |

### 9.3.6 L1-Detail Channel Bonding Parameters (PLP)

The following L1-Detail signaling fields are related to channel bonding on a PLP basis. These signaling fields shall not be included when **L1D_num_rf**=0.

**L1D_plp_num_channel_bonded** – This field shall indicate the number of frequencies, not including the frequency of the present channel, involved in channel bonding of the current PLP. **L1D_plp_num_channel_bonded** shall have a maximum value of **L1D_num_rf**. When the current PLP is not channel bonded this shall be indicated by **L1D_plp_num_channel_bonded**=0. For the current version of the specification **L1D_plp_num_channel_bonded** shall have a maximum value of 1 (i.e. bonding with one other channel).

**L1D_plp_bonded_rf_id** – This field shall indicate the RF ids (**L1D_rf_id** values, which are not signaled parameters) of the channels that are used for channel bonding with the current PLP. It shall only be included when **L1D_plp_num_channel_bonded** > 0.

**L1D_plp_channel_bonding_format** – This field shall indicate the channel bonding format for the current PLP according to Table 9.23. When a PLP is bonded between multiple RF channels, the same bonding format shall be used for that PLP in each of those RF channels.

**Table 9.23** Signaling Format for **L1D_plp_channel_bonding_format**

| Value | Meaning |
|---|---|
| 00 | Plain channel bonding |
| 01 | SNR averaged channel bonding |
| 10 | Reserved for future use |
| 11 | Reserved for future use |

### 9.3.7 L1-Detail MIMO Parameters (PLP)

The following L1-Detail signaling fields are related to MIMO on a PLP basis. These signaling fields shall not be included when **L1B_first_sub_mimo** or **L1D_mimo** (as appropriate for the current subframe) has a value of 0.

**L1D_plp_mimo_stream_combining** – This flag shall indicate whether the stream combining option of MIMO precoding is used in the given PLP, as described in Section L.5.1. A value of 1 shall indicate that stream combining is used, and a value of 0 shall indicate that the stream combining option is not used.

**L1D_plp_mimo_IQ_interleaving** – This flag shall indicate whether the IQ polarization interleaving option of MIMO precoding is used in the given PLP, as described in Section L.5.2. A value of 1 shall indicate that IQ polarization interleaving is used, and a value of 0 shall indicate that the IQ polarization interleaving option is not used.

**L1D_plp_mimo_PH** – This flag shall indicate whether the phase hopping option of MIMO precoding is used in the given PLP, as described in Section L.5.3. A value of 1 shall indicate that phase hopping is used, and a value of 0 shall indicate that the phase hopping option is not used.

### 9.3.8 L1-Detail Cell Multiplexing Parameters

The following L1-Detail signaling fields are related to cell multiplexing.

**L1D_plp_start** – This field shall be set equal to the index of the data cell that holds the first data cell of the current PLP in the current subframe.

**L1D_plp_type** – This flag shall be set to **L1D_plp_type**=0 when the current PLP is non-dispersed (i.e. all data cells of the current PLP have contiguous logical addresses and subslicing is not used for the current PLP) or to **L1D_plp_type**=1 when the current PLP is dispersed (i.e. not all data cells of the current PLP have contiguous logical addresses and subslicing is used for the current PLP). **L1D_plp_type** shall only be present when **L1D_plp_layer**=0 (i.e. only Core PLPs have a PLP type associated with them).

**L1D_plp_num_subslices** – This field shall only be included when **L1D_plp_type**=1 and shall be set equal to one less than the actual number of subslices used for the current PLP within the current subframe. **L1D_plp_num_subslices**=0 shall be a reserved value, since it is not possible for a dispersed PLP to have only one subslice. The maximum allowable value for **L1D_plp_num_subslices** shall be 16383, corresponding to 16384 actual subslices. **L1D_plp_num_subslices** shall be set for each dispersed PLP.

**L1D_plp_subslice_interval** – This field shall only be included when **L1D_plp_type**=1 and shall be set equal to the number of sequentially-indexed data cells measured from the beginning of a subslice for a PLP to the beginning of the next subslice for the same PLP. As an illustrative example, if **L1D_plp_start**=100 and **L1D_plp_subslice_interval**=250, then the first data cell of the

first subslice of the current PLP would be located at index 100, and the first data cell of the second subslice of the current PLP would be located at index 100+250=350. **L1D_plp_subslice_interval** shall be set for each dispersed PLP.

### 9.3.9 L1-Detail Time Interleaver (TI) Parameters

**L1D_plp_TI_extended_interleaving** – This flag shall indicate whether extended interleaving is used for this PLP. A value of 1 shall indicate that extended interleaving is used. A value of 0 shall indicate that extended interleaving is not used. A value of 1 shall not be selected when LDM is used.

#### 9.3.9.1 Convolutional Time Interleaver Mode Parameters

The following parameters shall indicate the configuration of the Convolutional Time Interleaver in CTI mode.

**L1D_plp_CTI_depth** – This field shall indicate the number of rows used in the Convolutional Time Interleaver. **L1D_plp_CTI_depth** shall be signaled according to Table 9.24.

**Table 9.24** Signaling Format for **L1D_plp_CTI_depth**

| Value | Number of Rows |
|---|---|
| 000 | 512 |
| 001 | 724 |
| 010 | 887 (non-extended interleaving) or 1254 (extended interleaving) |
| 011 | 1024 (non-extended interleaving) or 1448 (extended interleaving) |
| 100 | Reserved for future use |
| 101 | Reserved for future use |
| 110 | Reserved for future use |
| 111 | Reserved for future use |

**L1D_plp_CTI_start_row** – This field shall indicate the position of the commutator selector at the start of the subframe.

**L1D_plp_CTI_fec_block_start** – This field shall indicate the position, after the CTI, of the first cell of the first complete FEC Block, before the CTI, for the current PLP in the current or a subsequent subframe. This position shall be specified relative to the first cell of the current PLP leaving the CTI in the current subframe, for which the commutator is at position **L1D_plp_CTI_start_row**. **L1D_plp_CTI_fec_block_start** may exceed subframe boundaries and thus may indicate a position in the PLP data that belongs to a subsequent subframe. **L1D_plp_CTI_fec_block_start** shall be determined prior to cell multiplexing.

**L1D_plp_CTI_fec_block_start** can be determined as follows. Let C be the position of the first cell of the first complete FEC Block before the CTI of the current PLP in the current or a subsequent subframe, where the indexing of C starts at 0, where 0 corresponds to the first cell, before the CTI, of the current PLP. Note that C will also be equal to the number of cells that belong to the immediately preceding FEC Block of the PLP and which have not yet been input to the CTI. Then **L1D_plp_CTI_fec_block_start** = $C + N_{rows} \times$ ((**L1D_plp_CTI_start_row** + C) modulo $N_{rows}$). Figure 9.2 shows graphically the calculation of **L1D_plp_CTI_fec_block_start**.

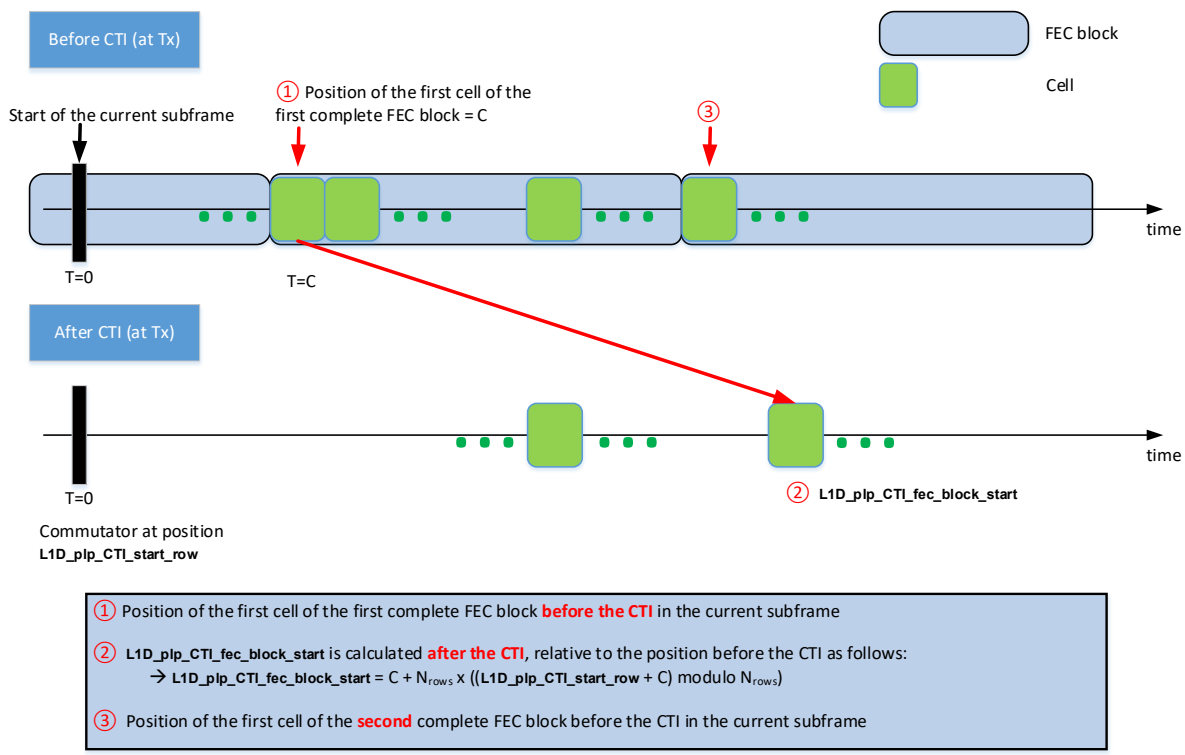


**Figure 9.2** **L1D_plp_CTI_fec_block_start** graphical description

When LDM is used, **L1D_plp_CTI_fec_block_start** shall be signaled separately for both Core PLPs and Enhanced PLPs since the start positions of the first complete FEC Blocks of Core PLPs and Enhanced PLPs that have been layered division multiplexed together are in general different.

#### 9.3.9.2 Hybrid Time Interleaver (Mode) Parameters

The following parameters shall indicate the configuration of the Hybrid Time Interleaver which shall be used when HTI mode is configured for the current PLP.

**L1D_plp_HTI_inter_subframe** – This field shall indicate the hybrid time interleaving mode. **L1D_plp_HTI_inter_subframe**=0 shall indicate that inter-subframe interleaving is not used (i.e. only intra-subframe interleaving is used). **L1D_plp_HTI_inter_subframe**=1 shall indicate that inter-subframe interleaving is used with one TI Block per interleaving frame spread over multiple subframes.

**L1D_plp_HTI_num_ti_blocks** – This field shall indicate either the number of TI Blocks per interleaving frame, $N_{TI}$, when **L1D_plp_HTI_inter_subframe**=0 or the number of subframes, $N_{IU}$, over which cells from one TI Block are carried when **L1D_plp_HTI_inter_subframe**=1. The value indicated by **L1D_plp_HTI_num_ti_blocks** shall be one less than the actual value of $N_{TI}$ or $N_{IU}$ to permit a range from 1 to 16 to be signaled.

**L1D_plp_HTI_num_fec_blocks_max** – This field shall indicate one less than the maximum number of FEC Blocks per interleaving frame for the current PLP.

**L1D_plp_HTI_num_fec_blocks** – This field shall indicate one less than the number of FEC Blocks contained in the current interleaving frame for the current PLP. When **L1D_plp_HTI_inter_subframe**=1 (i.e., when the HTI is configured for inter-subframe interleaving), **L1D_plp_HTI_num_fec_blocks** at index $k$=0 (in Table 9.8) indicates one less than the number of FEC Blocks in the interleaving frame that begins in the current subframe.

**L1D_plp_HTI_num_fec_blocks** at index $k$=1 indicates one less than the number of FEC Blocks in the interleaving frame that began in the previous subframe that contained the current PLP, and so on.

**L1D_plp_HTI_cell_interleaver** – This flag shall indicate whether the Cell Interleaver is used. A value of 1 shall indicate that the Cell Interleaver is used, and a value of 0 shall indicate that the Cell Interleaver is not used.

# *Annex A*: LDPC Codes

## A.1 LDPC CODE MATRICES ($N_{INNER}$ = 64800)

**Table A.1.1** Rate = 2/15 ($N_{inner}$ = 64800)

| |
|---|
| 615 898 1029 6129 8908 10620 13378 14359 21964 23319 26427 26690 28128 33435 36080 40697 43525 44498 50994 |
| 165 1081 1637 2913 8944 9639 11391 17341 22000 23580 32309 38495 41239 44079 47395 47460 48282 51744 52782 |
| 426 1340 1493 2261 10903 13336 14755 15244 20543 29822 35283 38846 45368 46642 46934 48242 49000 49204 53370 |
| 407 1059 1366 2004 5985 9217 9321 13576 19659 20808 30009 31094 32445 39094 39357 40651 44358 48755 49732 |
| 692 950 1444 2967 3929 6951 10157 10326 11547 13562 19634 34484 38236 42918 44685 46172 49694 50535 55109 |
| 1087 1458 1574 2335 3248 6965 17856 23454 25182 37359 37718 37768 38061 38728 39437 40710 46298 50707 51572 |
| 1098 1540 1711 7723 9549 9986 16369 19567 21185 21319 25750 32222 32463 40342 41391 43869 48372 52149 54722 |
| 514 1283 1635 6602 11333 11443 17690 21036 22936 24525 25425 27103 28733 29551 39204 42525 49200 54899 54961 |
| 357 609 1096 2954 4240 5397 8425 13974 15252 20167 20362 21623 27190 42744 47819 49096 51995 55504 55719 |
| 25 448 1501 11572 13478 24338 29198 29840 31428 33088 34724 37698 37988 38297 40482 46953 47880 53751 54943 |
| 328 1096 1262 10802 12797 16053 18038 20433 20444 25422 32992 34344 38326 41435 46802 48766 49807 52966 55751 |
| 34 790 987 5082 5788 10778 12824 18217 23278 24737 28312 34464 36765 37999 39603 40797 43237 53089 55319 |
| 226 1149 1470 3483 8949 9312 9773 13271 17804 20025 20323 30623 38575 39887 40305 46986 47223 49998 52111 |
| 1088 1091 1757 2682 5526 5716 9665 10733 12997 14440 24665 27990 30203 33173 37423 38934 40494 45418 48393 |
| 809 1278 1580 3486 4529 6117 6212 6823 7861 9244 11559 20736 30333 32450 35528 42968 44485 47149 54913 |
| 369 525 1622 2261 6454 10483 11259 16461 17031 20221 22710 25137 26622 27904 30884 31858 44121 50690 56000 |
| 423 1291 1352 7883 26107 26157 26876 27071 31515 35340 35953 36608 37795 37842 38527 41720 46206 47998 53019 |
| 540 662 1433 2828 14410 22880 24263 24802 28242 28396 35928 37214 39748 43915 44905 46590 48684 48890 55926 |
| 214 1291 1622 7311 8985 20952 22752 23261 24896 25057 28826 37074 37707 38742 46026 51116 51521 52956 54213 |
| 109 1305 1676 2594 7447 8943 14806 16462 19730 23430 24542 34300 36432 37133 41199 43942 45860 47598 48401 49407 |
| 242 388 1360 6721 14220 21029 22536 25126 32251 33182 39192 42436 44144 45252 46238 47369 47607 47695 50635 51469 |
| 199 958 1111 13661 18809 19234 21459 25221 25837 28256 36919 39031 39107 39262 43572 45018 45959 48006 52387 55811 |
| 668 1087 1451 2945 3319 12519 21248 21344 22627 22701 28152 29670 31430 32655 38533 42233 43200 44013 44459 51398 |
| 244 1133 1665 8222 8740 11285 12774 15922 20147 20978 28927 35086 40197 40583 41066 41223 42104 44650 45391 48437 |
| 5623 8050 9679 12978 15846 16049 21807 23364 27226 27758 28661 38147 46337 48141 51364 51927 55124 |
| 10369 13704 14491 18632 19430 21218 33392 36182 36722 37342 37415 46322 47449 51136 53392 54356 55108 |
| 7460 9411 11132 11739 13722 15501 25588 26463 26738 31980 31981 35002 39659 39783 41581 51358 55114 |
| 8915 15253 15264 16513 16896 18367 19110 23492 32074 33302 42443 43797 44715 47538 48515 53464 53548 |
| 5884 8910 10123 11311 13654 14207 16122 18113 23100 23784 24825 39629 46372 52454 52799 55039 55973 |

**Table A.1.2** Rate = 3/15 ($N_{inner}$ = 64800)

| | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 920 | 963 | 1307 | 2648 | 6529 | 17455 | 18883 | 19848 | 19909 | 24149 | 24249 | 38395 | 41589 | 48032 | 50313 |
| 297 | 736 | 744 | 5951 | 8438 | 9881 | 15522 | 16462 | 23036 | 25071 | 34915 | 41193 | 42975 | 43412 | 49612 |
| 10 | 223 | 879 | 4662 | 6400 | 8691 | 14561 | 16626 | 17408 | 22810 | 31795 | 32580 | 43639 | 45223 | 47511 |
| 629 | 842 | 1666 | 3150 | 7596 | 9465 | 12327 | 18649 | 19052 | 19279 | 29743 | 30197 | 40106 | 48371 | 51155 |
| 857 | 953 | 1116 | 8725 | 8726 | 10508 | 17112 | 21007 | 30649 | 32113 | 36962 | 39254 | 46636 | 49599 | 50099 |
| 700 | 894 | 1128 | 5527 | 6216 | 15123 | 21510 | 24584 | 29026 | 31416 | 37158 | 38460 | 42511 | 46932 | 51832 |
| 430 | 592 | 1521 | 3018 | 10430 | 18090 | 18092 | 18388 | 20017 | 34383 | 35006 | 38255 | 41700 | 42158 | 45211 |
| 91 | 1485 | 1733 | 11624 | 12969 | 17531 | 21324 | 23657 | 27148 | 27509 | 28753 | 35093 | 43352 | 48104 | 51648 |
| 18 | 34 | 117 | 6739 | 8679 | 11018 | 12163 | 16733 | 24113 | 25906 | 30605 | 32700 | 36465 | 40799 | 43359 |
| 481 | 1545 | 1644 | 4216 | 4606 | 6015 | 6609 | 14659 | 16966 | 18056 | 19137 | 26670 | 28001 | 30668 | 49061 |
| 174 | 1208 | 1387 | 10580 | 11507 | 13751 | 16344 | 22735 | 23559 | 26492 | 27672 | 33399 | 44787 | 44842 | 45992 |
| 1151 | 1185 | 1472 | 6727 | 10701 | 14755 | 15688 | 17441 | 21281 | 23692 | 23994 | 31366 | 35854 | 37301 | 43148 |
| 200 | 799 | 1583 | 3451 | 5880 | 7604 | 8194 | 13428 | 16109 | 18584 | 20463 | 22373 | 31977 | 47073 | 50087 |
| 346 | 843 | 1352 | 13409 | 17376 | 18233 | 19119 | 19382 | 20578 | 24183 | 32052 | 32912 | 43204 | 48539 | 49893 |
| 76 | 457 | 1169 | 13516 | 14520 | 14638 | 22391 | 25294 | 31067 | 31325 | 36711 | 44072 | 44854 | 49274 | 51624 |
| 759 | 798 | 1420 | 6661 | 12101 | 12573 | 13796 | 15510 | 18384 | 26649 | 30875 | 36856 | 38994 | 43634 | 49281 |
| 551 | 797 | 1000 | 3999 | 10040 | 11246 | 15793 | 23298 | 23822 | 38480 | 39209 | 45334 | 46603 | 46625 | 47633 |
| 441 | 875 | 1554 | 5336 | 25948 | 28842 | 30329 | 31503 | 39203 | 39673 | 46250 | 47021 | 48555 | 49229 | 51421 |
| 963 | 1470 | 1642 | 3180 | 3943 | 6513 | 9125 | 15641 | 17083 | 18876 | 28499 | 32764 | 42420 | 43922 | 45762 |
| 293 | 324 | 867 | 8803 | 10582 | 17926 | 19830 | 22497 | 24848 | 30034 | 34659 | 37721 | 41523 | 42534 | 47806 |
| 687 | 975 | 1356 | 2721 | 3002 | 3874 | 4119 | 12336 | 17119 | 21251 | 22482 | 22833 | 24681 | 26225 | 48514 |
| 549 | 951 | 1268 | 9144 | 11710 | 12623 | 18949 | 19362 | 22769 | 32603 | 34559 | 34683 | 36338 | 47140 | 51069 |
| 52 | 890 | 1669 | 3905 | 5670 | 14712 | 18314 | 22297 | 30328 | 33389 | 35447 | 35512 | 35516 | 40587 | 41918 |
| 656 | 1063 | 1694 | 3338 | 3793 | 4513 | 6009 | 7441 | 13393 | 20920 | 26501 | 27576 | 29623 | 31261 | 42093 |
| 425 | 1018 | 1086 | 9226 | 10024 | 17552 | 24714 | 24877 | 25853 | 28918 | 30945 | 31205 | 33103 | 42564 | 47214 |
| 32 | 1145 | 1438 | 4916 | 4945 | 14830 | 17505 | 19919 | 24118 | 28506 | 30173 | 31754 | 34230 | 48608 | 50291 |
| 559 | 1216 | 1272 | 2856 | 8703 | 9371 | 9708 | 16180 | 19127 | 24337 | 26390 | 36649 | 41105 | 42988 | 44096 |
| 362 | 658 | 1191 | 7769 | 8998 | 14068 | 15921 | 18471 | 18780 | 31995 | 32798 | 32864 | 37293 | 39468 | 44308 |
| 1136 | 1389 | 1785 | 8800 | 12541 | 14723 | 15210 | 15859 | 26569 | 30127 | 31357 | 32898 | 38760 | 50523 | 51715 |
| 44 | 80 | 1368 | 2010 | 2228 | 6614 | 6767 | 9275 | 25237 | 30208 | 39537 | 42041 | 49906 | 50701 | 51199 |
| 1522 | 1536 | 1765 | 3914 | 5350 | 10869 | 12278 | 12886 | 16379 | 22743 | 23987 | 26306 | 30966 | 33854 | 41356 |
| 212 | 648 | 709 | 3443 | 7007 | 7545 | 12484 | 13358 | 17008 | 20433 | 25862 | 31945 | 39207 | 39752 | 40313 |
| 789 | 1062 | 1431 | 12280 | 17415 | 18098 | 23729 | 37278 | 38454 | 38763 | 41039 | 44600 | 50700 | 51139 | 51696 |
| 825 | 1298 | 1391 | 4882 | 12738 | 17569 | 19177 | 19896 | 27401 | 37041 | 39181 | 39199 | 41832 | 43636 | 45775 |
| 992 | 1053 | 1485 | 3806 | 16929 | 18596 | 22017 | 23435 | 23932 | 30211 | 30390 | 34469 | 37213 | 46220 | 49646 |
| 771 | 850 | 1039 | 5180 | 7653 | 13547 | 17980 | 23365 | 25318 | 34374 | 36115 | 38753 | 42993 | 49696 | 51031 |
| 7383 | 14780 | 15959 | 18921 | 22579 | 28612 | 32038 | 36727 | 40851 | 41947 | 42707 | 50480 | | | |
| 8733 | 9464 | 13148 | 13899 | 19396 | 22933 | 23039 | 25047 | 29938 | 33588 | 33796 | 48930 | | | |
| 2493 | 12555 | 16706 | 23905 | 35400 | 36330 | 37065 | 38866 | 40305 | 43807 | 43917 | 50621 | | | |
| 6437 | 11927 | 14542 | 16617 | 17317 | 17755 | 18832 | 24772 | 29273 | 31136 | 36925 | 46663 | | | |
| 2191 | 3431 | 6288 | 6430 | 9908 | 13069 | 23014 | 24822 | 29818 | 39914 | 46010 | 47246 | | | |

**Table A.1.3** Rate = 4/15 ($N_{inner}$ = 64800)

| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 276 | 1754 | 1780 | 3597 | 8549 | 15196 | 26305 | 27003 | 33883 | 37189 | 41042 | 41849 | 42356 |
| 730 | 873 | 927 | 9310 | 9867 | 17594 | 21969 | 25106 | 25922 | 31167 | 35434 | 37742 | 45866 |
| 925 | 1202 | 1564 | 2575 | 2831 | 2951 | 5193 | 13096 | 18363 | 20592 | 33786 | 34090 | 40900 |
| 973 | 1045 | 1071 | 8545 | 8980 | 11983 | 18649 | 21323 | 22789 | 22843 | 26821 | 36720 | 37856 |
| 402 | 1038 | 1689 | 2466 | 2893 | 13474 | 15710 | 24137 | 29709 | 30451 | 35568 | 35966 | 46436 |
| 263 | 271 | 395 | 5089 | 5645 | 15488 | 16314 | 28778 | 29729 | 34350 | 34533 | 39608 | 45371 |
| 387 | 1059 | 1306 | 1955 | 6990 | 20001 | 24606 | 28167 | 33802 | 35181 | 38481 | 38688 | 45140 |
| 53 | 851 | 1750 | 3493 | 11415 | 18882 | 20244 | 23411 | 28715 | 30722 | 36487 | 38019 | 45416 |
| 810 | 1044 | 1772 | 3906 | 5832 | 16793 | 17333 | 17910 | 23946 | 29650 | 34190 | 40673 | 45828 |
| 97 | 491 | 948 | 12156 | 13788 | 24970 | 33774 | 37539 | 39750 | 39820 | 41195 | 46464 | 46820 |
| 192 | 899 | 1283 | 3732 | 7310 | 13637 | 13810 | 19005 | 24227 | 26772 | 31273 | 37665 | 44005 |
| 424 | 531 | 1300 | 4860 | 8983 | 10137 | 16323 | 16888 | 17933 | 22458 | 26917 | 27835 | 37931 |
| 130 | 279 | 731 | 3024 | 6378 | 18838 | 19746 | 21007 | 22825 | 23109 | 28644 | 32048 | 34667 |
| 938 | 1041 | 1482 | 9589 | 10065 | 11535 | 17477 | 25816 | 27966 | 35022 | 35025 | 42536 | |
| 170 | 454 | 1312 | 5326 | 6765 | 23408 | 24090 | 26072 | 33037 | 38088 | 42985 | 46413 | |
| 220 | 804 | 843 | 2921 | 4841 | 7760 | 8303 | 11259 | 21058 | 21276 | 34346 | 37604 | |
| 676 | 713 | 832 | 11937 | 12006 | 12309 | 16329 | 26438 | 34214 | 37471 | 38179 | 42420 | |
| 714 | 931 | 1580 | 6837 | 9824 | 11257 | 15556 | 26730 | 32053 | 34461 | 35889 | 45821 | |
| 28 | 1097 | 1340 | 8767 | 9406 | 17253 | 29558 | 32857 | 37856 | 38593 | 41781 | 47101 | |
| 158 | 722 | 754 | 14489 | 23851 | 28160 | 30371 | 30579 | 34963 | 44216 | 46462 | 47463 | |
| 833 | 1326 | 1332 | 7032 | 9566 | 11011 | 21424 | 26827 | 29789 | 31699 | 32876 | 37498 | |
| 251 | 504 | 1075 | 4470 | 7736 | 11242 | 20397 | 32719 | 34453 | 36571 | 40344 | 46341 | |
| 330 | 581 | 868 | 15168 | 20265 | 26354 | 33624 | 35134 | 38609 | 44965 | 45209 | 46909 | |
| 729 | 1643 | 1732 | 3946 | 4912 | 9615 | 19699 | 30993 | 33658 | 38712 | 39424 | 46799 | |
| 546 | 982 | 1274 | 9264 | 11017 | 11868 | 15674 | 16277 | 19204 | 28606 | 39063 | 43331 | |
| 73 | 1160 | 1196 | 4334 | 12560 | 13583 | 14703 | 18270 | 18719 | 19327 | 38985 | 46779 | |
| 1147 | 1625 | 1759 | 3767 | 5912 | 11599 | 18561 | 19330 | 29619 | 33671 | 43346 | 44098 | |
| 104 | 1507 | 1586 | 9387 | 17890 | 23532 | 27008 | 27861 | 30966 | 33579 | 35541 | 39801 | |
| 1700 | 1746 | 1793 | 4941 | 7814 | 13746 | 20375 | 27441 | 30262 | 30392 | 35385 | 42848 | |
| 183 | 555 | 1029 | 3090 | 5412 | 8148 | 19662 | 23312 | 23933 | 28179 | 29962 | 35514 | |
| 891 | 908 | 1127 | 2827 | 4077 | 4376 | 4570 | 26923 | 27456 | 33699 | 43431 | 46071 | |
| 404 | 1110 | 1782 | 6003 | 14452 | 19247 | 26998 | 30137 | 31404 | 31624 | 46621 | 47366 | |
| 886 | 1627 | 1704 | 8193 | 8980 | 9648 | 10928 | 16267 | 19774 | 35111 | 38545 | 44735 | |
| 268 | 380 | 1214 | 4797 | 5168 | 9109 | 9288 | 17992 | 21309 | 33210 | 36210 | 41429 | |
| 572 | 1121 | 1165 | 6944 | 7114 | 20978 | 23540 | 25863 | 26190 | 26365 | 41521 | 44690 | |
| 18 | 185 | 496 | 5885 | 6165 | 20468 | 23895 | 24745 | 31226 | 33680 | 37665 | 38587 | |
| 289 | 527 | 1118 | 11275 | 12015 | 18088 | 22805 | 24679 | 28262 | 30160 | 34892 | 43212 | |
| 658 | 926 | 1589 | 7634 | 16231 | 22193 | 25320 | 26057 | 26512 | 27498 | 29472 | 34219 | |
| 337 | 801 | 1525 | 2023 | 3512 | 16031 | 26911 | 32719 | 35620 | 39035 | 43779 | 44316 | |
| 248 | 534 | 670 | 6217 | 11430 | 24090 | 26509 | 28712 | 33073 | 33912 | 38048 | 39813 | |
| 82 | 1556 | 1575 | 7879 | 7892 | 14714 | 22404 | 22773 | 25531 | 34170 | 38203 | 38254 | |
| 247 | 313 | 1224 | 3694 | 14304 | 24033 | 26394 | 28101 | 37455 | 37859 | 38997 | 41344 | |
| 790 | 887 | 1418 | 2811 | 3288 | 9049 | 9704 | 13303 | 14262 | 38149 | 40109 | 40477 | |
| 1310 | 1384 | 1471 | 3716 | 8250 | 25371 | 26329 | 26997 | 30138 | 40842 | 41041 | 44921 | |
| 86 | 288 | 367 | 1860 | 8713 | 18211 | 22628 | 22811 | 28342 | 28463 | 40415 | 45845 | |
| 719 | 1438 | 1741 | 8258 | 10797 | 29270 | 29404 | 32096 | 34433 | 34616 | 36030 | 45597 | |
| 215 | 1182 | 1364 | 8146 | 9949 | 10498 | 18603 | 19304 | 19803 | 23685 | 43304 | 45121 | |
| 1243 | 1496 | 1537 | 8484 | 8851 | 16589 | 17665 | 20152 | 24283 | 28993 | 34274 | 39795 | |
| 6320 | 6785 | 15841 | 16309 | 20512 | 25804 | 27421 | 28941 | 43871 | 44647 | | | |
| 2207 | 2713 | 4450 | 12217 | 16506 | 21188 | 23933 | 28789 | 38099 | 42392 | | | |
| 14064 | 14307 | 14599 | 14866 | 17540 | 18881 | 21065 | 25823 | 30341 | 36963 | | | |
| 14259 | 14396 | 17037 | 26769 | 29219 | 29319 | 31689 | 33013 | 35631 | 37319 | | | |
| 7798 | 10495 | 12868 | 14298 | 17221 | 23344 | 31908 | 39809 | 41001 | 41965 | | | |

**Table A.1.4** Rate = 5/15 ($N_{inner}$ = 64800)

221 1011 1218 4299 7143 8728 11072 15533 17356 33909 36833
360 1210 1375 2313 3493 16822 21373 23588 23656 26267 34098
544 1347 1433 2457 9186 10945 13583 14858 19195 34606 37441
37 596 715 4134 8091 12106 24307 24658 34108 40591 42883
235 398 1204 2075 6742 11670 13512 23231 24784 27915 34752
204 873 890 13550 16570 19774 34012 35249 37655 39885 42890
221 371 514 11984 14972 15690 28827 29069 30531 31018 43121
280 549 1435 1889 3310 10234 11575 15243 20748 30469 36005
223 666 1248 13304 14433 14732 18943 21248 23127 38529 39272
370 819 1065 9461 10319 25294 31958 33542 37458 39681 40039
585 870 1028 5087 5216 12228 16216 16381 16937 27132 27893
164 167 1210 7386 11151 20413 22713 23134 24188 36771 38992
298 511 809 4620 7347 8873 19602 24162 29198 34304 41145
105 830 1212 2415 14759 15440 16361 16748 22123 32684 42575
659 665 668 6458 22130 25972 30697 31074 32048 36078 37129
91 808 953 8015 8988 13492 13987 15979 28355 34509 39698
594 983 1265 3028 4029 9366 11069 11512 27066 40939 41639
506 740 1321 1484 10747 16376 17384 20285 31502 38925 42606
338 356 975 2022 3578 18689 18772 19826 22914 24733 27431
709 1264 1366 4617 8893 25226 27800 29080 30277 37781 39644
840 1179 1338 2973 3541 7043 12712 15005 17149 19910 36795
1009 1267 1380 4919 12679 22889 29638 30987 34637 36232 37284
466 913 1247 1646 3049 5924 9014 20539 34546 35029 36540
374 697 984 1654 5870 10883 11684 20294 28888 31612 34031
117 240 635 5093 8673 11323 12456 14145 21397 39619 42559
122 1265 1427 13528 14282 15241 16852 17227 34723 36836 39791
595 1180 1310 6952 17916 24725 24971 27243 29555 32138 35987
140 470 1017 13222 13253 18462 20806 21117 28673 31598 37235
7 710 1072 8014 10804 13303 14292 16690 26676 36443 41966
48 189 759 12438 14523 16388 23178 27315 28656 29111 29694
285 387 410 4294 4467 5949 25386 27898 34880 41169 42614
474 545 1320 10506 13186 18126 27110 31498 35353 36193 37322
1075 1130 1424 11390 13312 14161 16927 25071 25844 34287 38151
161 396 427 5944 17281 22201 25218 30143 35566 38261 42513
233 247 694 1446 3180 3507 9069 20764 21940 33422 39358
271 508 1013 6271 21760 21858 24887 29808 31099 35475 39924
8 674 1329 3135 5110 14460 28108 28388 31043 31137 31863
1035 1222 1409 8287 16083 24450 24888 29356 30329 37834 39684
391 1090 1128 1866 4095 10643 13121 14499 20056 22195 30593
55 161 1402 6289 6837 8791 17937 21425 26602 30461 37241
110 377 1228 6875 13253 17032 19008 23274 32285 33452 41630
360 638 1355 5933 12593 13533 23377 23881 24586 26040 41663
535 1240 1333 3354 10860 16032 32573 34908 34957 39255 40759
526 936 1321 7992 10260 18527 28248 29356 32636 34666 35552
336 785 875 7530 13062 13075 18925 27963 28703 33688 36502
36 591 1062 1518 3821 7048 11197 17781 19408 22731 24783
214 1145 1223 1546 9475 11170 16061 21273 38688 40051 42479
1136 1226 1423 20227 22573 24951 26462 29586 34915 42441 43048
26 276 1425 6048 7224 7917 8747 27559 28515 35002 37649
127 294 437 4029 8585 9647 11904 24115 28514 36893 39722
748 1093 1403 9536 19305 20468 31049 38667 40502 40720 41949
96 638 743 9806 12101 17751 22732 24937 32007 32594 38504
649 904 1079 2770 3337 9158 20125 24619 32921 33698 35173
401 518 984 7372 12438 12582 18704 35874 39420 39503 39790
10 451 1077 8078 16320 17409 25807 28814 30613 41261 42955
405 592 1178 15936 18418 19585 21966 24219 30637 34536 37838
50 584 851 9720 11919 22544 22545 25851 35567 41587 41876
911 1113 1176 1806 10058 10809 14220 19044 20748 29424 36671
441 550 1135 1956 11254 18699 30249 33099 34587 35243 39952
510 1016 1281 8621 13467 13780 15170 16289 20925 26426 34479
4969 5223 17117 21950 22144 24043 27151 39809
11452 13622 18918 19670 23995 32647 37200 37399
6351 6426 13185 13973 16699 22524 31070 31916
4098 10617 14854 18004 28580 36158 37500 38552

**Table A.1.5** Rate = 6/15 ($N_{inner}$ = 64800)

1606 3402 4961 6751 7132 11516 12300 12482 12592 13342 13764 14123 21576 23946 24533 25376 25667 26836 31799 34173 35462 36153 36740 37085 37152 37468 37658
4621 5007 6910 8732 9757 11508 13099 15513 16335 18052 19512 21319 23663 25628 27208 31333 32219 33003 33239 33447 36200 36473 36938 37201 37283 37495 38642
16 1094 2020 3080 4194 5098 5631 6877 7889 8237 9804 10067 11017 11366 13136 13354 15379 18934 20199 24522 26172 28666 30386 32714 36390 37015 37162
700 897 1708 6017 6490 7372 7825 9546 10398 16605 18561 18745 21625 22137 23693 24340 24966 25015 26995 28586 28895 29687 33938 34520 34858 37056 38297
159 2010 2573 3617 4452 4958 5556 5832 6481 8227 9924 10836 14954 15594 16623 18065 19249 22394 22677 23408 23731 24076 24776 27007 28222 30343 38371
3118 3545 4768 4992 5227 6732 8170 9397 10522 11508 15536 20218 21921 28599 29445 29758 29968 31014 32027 33685 34378 35867 36323 36728 36870 38335 38623
1264 4254 6936 9165 9486 9950 10861 11653 13697 13961 15164 15665 18444 19470 20313 21189 24371 26431 26999 28086 28251 29261 31981 34015 35850 36129 37186
111 1307 1628 2041 2524 5358 7988 8191 10322 11905 12919 14127 15515 15711 17061 19024 21195 22902 23727 24401 24608 25111 25228 27338 35398 37794 38196
961 3035 7174 7948 13355 13607 14971 18189 18339 18665 18875 19142 20615 21136 21309 21758 23366 24745 25849 25982 27583 30006 31118 32106 36469 36583 37920
2990 3549 4273 4808 5707 6021 6509 7456 8240 10044 12262 12660 13085 14750 15680 16049 21587 23997 25803 28343 28693 34393 34860 35490 36021 37737 38296
955 4323 5145 6885 8123 9730 11840 12216 19194 20313 23056 24248 24830 25268 26617 26801 28557 29753 30745 31450 31973 32839 33025 33296 35710 37366 37509
264 605 4181 4483 5156 7238 8863 10939 11251 12964 16254 17511 20017 22395 22818 23261 23422 24064 26329 27723 28186 30434 31956 33971 34372 36764 38123
520 2562 2794 3528 3860 4402 5676 6963 8655 9018 9783 11933 16336 17193 17320 19035 20606 23579 23769 24123 24966 27866 32457 34011 34499 36620 37526
10106 10637 10906 34242
1856 15100 19378 21848
943 11191 27806 29411
4575 6359 13629 19383
4476 4953 18782 24313
5441 6381 21840 35943
9638 9763 12546 30120
9587 10626 11047 25700
4088 15298 28768 35047
2332 6363 8782 28863
4625 4933 28298 30289
3541 4918 18257 31746
1221 25233 26757 34892
8150 16677 27934 30021
8500 25016 33043 38070
7374 10207 16189 35811
611 18480 20064 38261
25416 27352 36089 38469
1667 17614 25839 32776
4118 12481 21912 37945
5573 13222 23619 31271
18271 26251 27182 30587
14690 26430 26799 34355
13688 16040 20716 34558
2740 14957 23436 32540
3491 14365 14681 36858
4796 6238 25203 27854
1731 12816 17344 26025
19182 21662 23742 27872
6502 13641 17509 34713
12246 12372 16746 27452
1589 21528 30621 34003
12328 20515 30651 31432
3415 22656 23427 36395
632 5209 25958 31085
619 3690 19648 37778
9528 13581 26965 36447
2147 26249 26968 28776
15698 18209 30683
1132 19888 34111
4608 25513 38874
475 1729 34100
7348 32277 38587
182 16473 33082
3865 9678 21265
4447 20151 27618
6335 14371 38711
704 9695 28858
4856 9757 30546
1993 19361 30732
756 28000 29138
3821 24076 31813
4611 12326 32291
7628 21515 34995
1246 13294 30068
6466 33233 35865
14484 23274 38150
21269 36411 37450
23129 26195 37653

**Table A.1.6** Rate = 7/15 ($N_{inner}$ = 64800)

460 792 1007 4580 11452 13130 26882 27020 32439
35 472 1056 7154 12700 13326 13414 16828 19102
45 440 772 4854 7863 26945 27684 28651 31875
744 812 892 1509 9018 12925 14140 21357 25106
271 474 761 4268 6706 9609 19701 19707 24870
223 477 662 1987 9247 18376 22148 24948 27694
44 379 786 8823 12322 14666 16377 28688 29924
104 219 562 5832 19665 20615 21043 22759 32180
41 43 870 7963 13718 14136 17216 30470 33428
592 744 887 4513 6192 18116 19482 25032 34095
456 821 1078 7162 7443 8774 15567 17243 33085
151 666 977 6946 10358 11172 18129 19777 32234
236 793 870 2001 6805 9047 13877 30131 34252
297 698 772 3449 4204 11608 22950 26071 27512
202 428 474 3205 3726 6223 7708 20214 25283
139 719 915 1447 2938 11864 15932 21748 28598
135 853 902 3239 18590 20579 30578 33374 34045
9 13 971 11834 13642 17628 21669 24741 30965
344 531 730 1880 16895 17587 21901 28620 31957
7 192 380 3168 3729 5518 6827 20372 34168
28 521 681 4313 7465 14209 21501 23364 25980
269 393 898 3561 11066 11985 17311 26127 30309
42 82 707 4880 4890 9818 23340 25959 31695
189 262 707 6573 14082 22259 24230 24390 24664
383 568 573 5498 13449 13990 16904 22629 34203
585 596 820 2440 2488 21956 28261 28703 29591
755 763 795 5636 16433 21714 23452 31150 34545
23 343 669 1159 3507 13096 17978 24241 34321
316 384 944 4872 8491 18913 21085 23198 24798
64 314 765 3706 7136 8634 14227 17127 23437
220 693 899 8791 12417 13487 18335 22126 27428
285 794 1045 8624 8801 9547 19167 21894 32657
386 621 1045 1634 1882 3172 13686 16027 22448
95 622 693 2827 7098 11452 14112 18831 31308
446 813 928 7976 8935 13146 27117 27766 33111
89 138 241 3218 9283 20458 31484 31538 34216
277 420 704 9281 12576 12788 14496 15357 20585
141 643 758 4894 10264 15144 16357 22478 26461
17 108 160 13183 15424 17939 19276 23714 26655
109 285 608 1682 20223 21791 24615 29622 31983
123 515 622 7037 13946 15292 15606 16262 23742
264 565 923 6460 13622 13934 23181 25475 26134
202 548 789 8003 10993 12478 16051 25114 27579
121 450 575 5972 10062 18693 21852 23874 28031
507 560 889 12064 13316 19629 21547 25461 28732
664 786 1043 9137 9294 10163 23389 31436 34297
45 830 907 10730 16541 21232 30354 30605 31847
203 507 1060 6971 12216 13321 17861 22671 29825
369 881 952 3035 12279 12775 17682 17805 34281
683 709 1032 3787 17623 24138 26775 31432 33626
524 792 1042 12249 14765 18601 25811 32422 33163
137 639 688 7182 8169 10443 22530 24597 29039
159 643 749 16386 17401 24135 28429 33468 33469
107 481 555 7322 13234 19344 23498 26581 31378
249 389 523 3421 10150 17616 19085 20545 32069
395 738 1045 2415 3005 3820 19541 23543 31068
27 293 703 1717 3460 8326 8501 10290 32625
126 247 515 6031 9549 10643 22067 29490 34450
331 471 1007 3020 3922 7580 23358 28620 30946
222 542 1021 3291 3652 13130 16349 33009 34348
532 719 1038 5891 7528 23252 25472 31395 31774
145 398 774 7816 13887 14936 23708 31712 33160
88 536 600 1239 1887 12195 13782 16726 27998
151 269 585 1445 3178 3970 15568 20358 21051
650 819 865 15567 18546 25571 32038 33350 33620
93 469 800 6059 10405 12296 17515 21354 22231
97 206 951 6161 16376 27022 29192 30190 30665
412 549 986 5833 10583 10766 24946 28878 31937
72 604 659 5267 12227 21714 32120 33472 33974
25 902 912 1137 2975 9642 11598 25919 28278
420 976 1055 8473 11512 20198 21662 25443 30119
1 24 932 6426 11899 13217 13935 16548 29737
53 618 988 6280 7267 11676 13575 15532 25787
111 739 809 8133 12717 12741 20253 20608 27850
120 683 943 14496 15162 15440 18660 27543 32404
600 754 1055 7873 9679 17351 27268 33508
344 756 1054 7102 7193 22903 24720 27883
582 1003 1046 11344 23756 27497 27977 32853
28 429 509 11106 11767 12729 13100 31792
131 555 907 5113 10259 10300 20580 23029
406 915 977 12244 20259 26616 27899 32228
46 195 224 1229 4116 10263 13608 17830
19 819 953 7965 9998 13959 30580 30754
164 1003 1032 12920 15975 16582 22624 27357
8433 11894 13531 17675 25889 31384
3166 3813 8596 10368 25104 29584
2466 8241 12424 13376 24837 32711

**Table A.1.7** Rate = 8/15 ($N_{inner}$ = 64800)

| | |
|---|---|
| 2768 3039 4059 5856 6245 7013 8157 9341 9802 10470 11521 12083 16610 18361 20321 24601 27420 28206 29788 | 5496 15681 21854 |
| 2739 8244 8891 9157 12624 12973 15534 16622 16919 18402 18780 19854 20220 20543 22306 25540 27478 27678 28053 | 12697 13407 22178 |
| 1727 2268 6246 7815 9010 9556 10134 10472 11389 14599 15719 16204 17342 17666 18850 22058 25579 25860 29207 | 12788 21227 22894 |
| 28 1346 3721 5565 7019 9240 12355 13109 14800 16040 16839 17369 17631 19357 19473 19891 20381 23911 29683 | 629 2854 6232 |
| 869 2450 4386 5316 6160 7107 10362 11132 11271 13149 16397 16532 17113 19894 22043 22784 27383 28615 28804 | 2289 18227 27458 |
| 508 4292 5831 8559 10044 10412 11283 14810 15888 17243 17538 19903 20528 22090 22652 27235 27384 28208 28485 | 7593 21935 23001 |
| 389 2248 5840 6043 7000 9054 11075 11760 12217 12565 13587 15403 19422 19528 21493 25142 27777 28566 28702 | 3836 7081 12282 |
| 1015 2002 5764 6777 9346 9629 11039 11153 12690 13068 13990 16841 17702 20021 24106 26300 29332 30081 30196 | 7925 18440 23135 |
| 1480 3084 3467 4401 4798 5187 7851 11368 12323 14325 14546 16360 17158 18010 21333 25612 26556 26906 27005 | 497 6342 9717 |
| 6925 8876 12392 14529 15253 15437 19226 19950 20321 23021 23651 24393 24653 26668 27205 28269 28529 29041 29292 | 11199 22046 30067 |
| 2547 3404 3538 4666 5126 5468 7695 8799 14732 15072 15881 17410 18971 19609 19717 22150 24941 27908 29018 | 12572 28045 28990 |
| 888 1581 2311 5511 7218 9107 10454 12252 13662 15714 15894 17025 18671 24304 25316 25556 28489 28977 29212 | 1240 2023 10933 |
| 1047 1494 1718 4645 5030 6811 7868 8146 10611 15767 17682 18391 22614 23021 23763 25478 26491 29088 29757 | 19566 20629 25186 |
| 59 1781 1900 3814 4121 8044 8906 9175 11156 14841 15789 16033 16755 17292 18550 19310 22505 29567 29850 | 6442 13303 28813 |
| 1952 3057 4399 9476 10171 10769 11335 11569 15002 19501 20621 22642 23452 24360 25109 25290 25828 28505 29122 | 4765 10572 16180 |
| 2895 3070 3437 4764 4905 6670 9244 11845 13352 13573 13975 14600 15871 17996 19672 20079 20579 25327 27958 | 552 19301 24286 |
| 612 1528 2004 4244 4599 4926 5843 7684 10122 10443 12267 14368 18413 19058 22985 24257 26202 26596 27899 | 6782 18480 21383 |
| 1361 2195 4146 6708 7158 7538 9138 9998 14862 15359 16076 18925 21401 21573 22503 24146 24247 27778 29312 | 11267 12288 15758 |
| 5229 6235 7134 7655 9139 13527 15408 16058 16705 18320 19909 20901 22238 22437 23654 25131 27550 28247 29903 | 771 5652 15531 |
| 697 2035 4887 5275 6909 9166 11805 15338 16381 18403 20425 20688 21547 24590 25171 26726 28848 29224 29412 | 16131 20047 25649 |
| 5379 17329 22659 23062 | 13227 23035 24450 |
| 11814 14759 22329 22936 | 4839 13467 27488 |
| 2423 2811 10296 12727 | 2852 4677 22993 |
| 8460 15260 16769 17290 | 2504 28116 29524 |
| 14191 14608 29536 30187 | 12518 17374 24267 |
| 7103 10069 20111 22850 | 1222 11859 27922 |
| 4285 15413 26448 29069 | 9660 17286 18261 |
| 548 2137 9189 10928 | 232 11296 29978 |
| 4581 7077 23382 23949 | 9750 11165 16295 |
| 3942 17248 19486 27922 | 4894 9505 23622 |
| 8668 10230 16922 26678 | 10861 11980 14110 |
| 6158 9980 13788 28198 | 2128 15883 22836 |
| 12422 16076 24206 29887 | 6274 17243 21989 |
| 8778 10649 18747 22111 | 10866 13202 22517 |
| 21029 22677 27150 28980 | 11159 16111 21608 |
| 7918 15423 27672 27803 | 3719 18787 22100 |
| 5927 18086 23525 | 1756 2020 23901 |
| 3397 15058 30224 | 20913 29473 30103 |
| 24016 25880 26268 | 2729 15091 26976 |
| 1096 4775 7912 | 4410 8217 12963 |
| 3259 17301 20802 | 5395 24564 28235 |
| 129 8396 15132 | 3859 17909 23051 |
| 17825 28119 28676 | 5733 26005 29797 |
| 2343 8382 28840 | 1935 3492 29773 |
| 3907 18374 20939 | 11903 21380 29914 |
| 1132 1290 8786 | 6091 10469 29997 |
| 1481 4710 28846 | 2895 8930 15594 |
| 2185 3705 26834 | 1827 10028 20070 |

**Table A.1.8** Rate = 9/15 ($N_{inner}$ = 64800)

| | |
|---|---|
| 113 1557 3316 5680 6241 10407 13404 13947 14040 14353 15522 15698 16079 17363 19374 19543 20530 22833 24339 | 56 4564 19121 |
| 271 1361 6236 7006 7307 7333 12768 15441 15568 17923 18341 20321 21502 22023 23938 25351 25590 25876 25910 | 5595 15086 25892 |
| 73 605 872 4008 6279 7653 10346 10799 12482 12935 13604 15909 16526 19782 20506 22804 23629 24859 25600 | 3174 17127 23183 |
| 1445 1690 4304 4851 8919 9176 9252 13783 16076 16675 17274 18806 18882 20819 21958 22451 23869 23999 24177 | 19397 19817 20275 |
| 1290 2337 5661 6371 8996 10102 10941 11360 12242 14918 16808 20571 23374 24046 25045 25060 25662 25783 25913 | 12561 24571 25825 |
| 28 42 1926 3421 3503 8558 9453 10168 15820 17473 19571 19685 22790 23336 23367 23890 24061 25657 25680 | 7111 9889 25865 |
| 0 1709 4041 4932 5968 7123 8430 9564 10596 11026 14761 19484 20762 20858 23803 24016 24795 25853 25863 | 19104 20189 21851 |
| 29 1625 6500 6609 16831 18517 18568 18738 19387 20159 20544 21603 21941 24137 24269 24416 24803 25154 25395 | 549 9686 25548 |
| 55 66 871 3700 11426 13221 15001 16367 17601 18380 22796 23488 23938 25476 25635 25678 25807 25857 25872 | 6586 20325 25906 |
| 1 19 5958 8548 8860 11489 16845 18450 18469 19496 20190 23173 25262 25566 25668 25679 25858 25888 25915 | 3224 20710 21637 |
| 7520 7690 8855 9183 14654 16695 17121 17854 18083 18428 19633 20470 20736 21720 22335 23273 25083 25293 25403 | 641 15215 25754 |
| 48 58 410 1299 3786 10668 18523 18963 20864 22106 22308 23033 23107 23128 23990 24286 24409 24595 25802 | 13484 23729 25818 |
| 12 51 3894 6539 8276 10885 11644 12777 13427 14039 15954 17078 19053 20537 22863 24521 25087 25463 25838 | 2043 7493 24246 |
| 3509 8748 9581 11509 15884 16230 17583 19264 20900 21001 21310 22547 22756 22959 24768 24814 25594 25626 25880 | 16860 25230 25768 |
| 21 29 69 1448 2386 4601 6626 6667 10242 13141 13852 14137 18640 19951 22449 23454 24431 25512 25814 | 22047 24200 24902 |
| 18 53 7890 9934 10063 16728 19040 19809 20825 21522 21800 23582 24556 25031 25547 25562 25733 25789 25906 | 9391 18040 19499 |
| 4096 4582 5766 5894 6517 10027 12182 13247 15207 17041 18958 20133 20503 22228 24332 24613 25689 25855 25883 | 7855 24336 25069 |
| 0 25 819 5539 7076 7536 7695 9532 13668 15051 17683 19665 20253 21996 24136 24890 25758 25784 25807 | 23834 25570 25852 |
| 34 40 44 4215 6076 7427 7965 8777 11017 15593 19542 22202 22973 23397 23423 24418 24873 25107 25644 | 1977 8800 25756 |
| 1595 6216 22850 25439 | 6671 21772 25859 |
| 1562 15172 19517 22362 | 3279 6710 24444 |
| 7508 12879 24324 24496 | 24099 25117 25820 |
| 6298 15819 16757 18721 | 5553 12306 25915 |
| 11173 15175 19966 21195 | 48 11107 23907 |
| 59 13505 16941 23793 | 10832 11974 25773 |
| 2267 4830 12023 20587 | 2223 17905 25484 |
| 8827 9278 13072 16664 | 16782 17135 20446 |
| 14419 17463 23398 25348 | 475 2861 3457 |
| 6112 16534 20423 22698 | 16218 22449 24362 |
| 493 8914 21103 24799 | 11716 22200 25897 |
| 6896 12761 13206 25873 | 8315 15009 22633 |
| 2 1380 12322 21701 | 13 20480 25852 |
| 11600 21306 25753 25790 | 12352 18658 25687 |
| 8421 13076 14271 15401 | 3681 14794 23703 |
| 9630 14112 19017 20955 | 30 24531 25846 |
| 212 13932 21781 25824 | 4103 22077 24107 |
| 5961 9110 16654 19636 | 23837 25622 25812 |
| 58 5434 9936 12770 | 3627 13387 25839 |
| 6575 11433 19798 | 908 5367 19388 |
| 2731 7338 20926 | 0 6894 25795 |
| 14253 18463 25404 | 20322 23546 25181 |
| 21791 24805 25869 | 8178 25260 25437 |
| 2 11646 15850 | 2449 13244 22565 |
| 6075 8586 23819 | 31 18928 22741 |
| 18435 22093 24852 | 1312 5134 14838 |
| 2103 2368 11704 | 6085 13937 24220 |
| 10925 17402 18232 | 66 14633 25670 |
| 9062 25061 25674 | 47 22512 25472 |
| 18497 20853 23404 | 8867 24704 25279 |
| 18606 19364 19551 | 6742 21623 22745 |
| 7 1022 25543 | 147 9948 24178 |
| 6744 15481 25868 | 8522 24261 24307 |
| 9081 17305 25164 | 19202 22406 24609 |
| 8 23701 25883 | |
| 9680 19955 22848 | |

**Table A.1.9** Rate = 10/15 ($N_{inner}$ = 64800)

| | |
|---|---|
| 316 1271 3692 9495 12147 12849 14928 16671 16938 17864 19108 20502 21097 21115 | 615 1249 4639 |
| 2341 2559 2643 2816 2865 5137 5331 7000 7523 8023 10439 10797 13208 15041 | 3821 12073 18506 |
| 5556 6858 7677 10162 10207 11349 12321 12398 14787 15743 15859 15952 19313 20879 | 1066 16522 21536 |
| 349 573 910 2702 3654 6214 9246 9353 10638 11772 14447 14953 16620 19888 | 11307 18363 19740 |
| 204 1390 2887 3835 6230 6533 7443 7876 9299 10291 10896 13960 18287 20086 | 3240 8560 10391 |
| 541 2429 2838 7144 8523 8637 10490 10585 11074 12074 15762 16812 17900 18548 | 3124 11424 20779 |
| 733 1659 3838 5323 5805 7882 9429 10682 13697 16909 18846 19587 19592 20904 | 1604 8861 17394 |
| 1134 2136 4631 4653 4718 5197 10410 11666 14996 15305 16048 17417 18960 20303 | 2083 7400 8093 |
| 734 1001 1283 4959 10016 10176 10973 11578 12051 15550 15915 19022 19430 20121 | 3218 7454 9155 |
| 745 4057 5855 9885 10594 10989 13156 13219 13351 13631 13685 14577 17713 20386 | 9855 15998 20533 |
| 968 1446 2130 2502 3092 3787 5323 8104 8418 9998 11681 13972 17747 17929 | 316 2850 20652 |
| 3020 3857 5275 5786 6319 8608 11943 14062 17144 17752 18001 18453 19311 21414 | 5583 9768 10333 |
| 709 747 1038 2181 5320 8292 10584 10859 13964 15009 15277 16953 20675 21509 | 7147 7713 18339 |
| 1663 3247 5003 5760 7186 7360 10346 14211 14717 14792 15155 16128 17355 17970 | 12607 17428 21418 |
| 516 578 1914 6147 9419 11148 11434 13289 13325 13332 19106 19257 20962 21556 | 14216 16954 18164 |
| 5009 5632 6531 9430 9886 10621 11765 13969 16178 16413 18110 18249 20616 20759 | 8477 15970 18488 |
| 457 2686 3318 4608 5620 5858 6480 7430 9602 12691 14664 18777 20152 20848 | 1632 8032 9751 |
| 33 2877 5334 6851 7907 8654 10688 15401 16123 17942 17969 18747 18931 20224 | 4573 9080 13507 |
| 87 897 7636 8663 11425 12288 12672 14199 16435 17615 17950 18953 19667 20281 | 11747 12441 13876 |
| 1042 1832 2545 2719 2947 3672 3700 6249 6398 6833 11114 14283 17694 20477 | 1183 15605 16675 |
| 326 488 2662 2880 3009 5357 6587 8882 11604 14374 18781 19051 19057 20508 | 4408 10264 17109 |
| 854 1294 2436 2852 4903 6466 7761 9072 9564 10321 13638 15658 16946 19119 | 5495 7882 12150 |
| 194 899 1711 2408 2786 5391 7108 8079 8716 11453 17303 19484 20989 21389 | 1010 3763 5065 |
| 1631 3121 3994 5005 7810 8850 10315 10589 13407 17162 18624 18758 19311 20301 | 9828 18054 21599 |
| 736 2424 4792 5600 6370 10061 16053 16775 18600 | 6342 7353 15358 |
| 1254 8163 8876 9157 12141 14587 16545 17175 18191 | 6362 9462 19999 |
| 388 6641 8974 10607 10716 14477 16825 17191 18400 | 7184 13693 17622 |
| 5578 6082 6824 7360 7745 8655 11402 11665 12428 | 4343 4654 10995 |
| 3603 8729 13463 14698 15210 19112 19550 20727 21052 | 7099 8466 18520 |
| 48 1732 3805 5158 15442 16909 19854 21071 21579 | 11505 14395 15138 |
| 11707 14014 21531 | 6779 16691 18726 |
| 1542 4133 4925 | 7146 12644 20196 |
| 10083 13505 21198 | 5865 16728 19634 |
| 14300 15765 16752 | 4657 8714 21246 |
| 778 1237 11215 | 4580 5279 18750 |
| 1325 3199 14534 | 3767 6620 18905 |
| 2007 14510 20599 | 9209 13093 17575 |
| 1996 5881 16429 | 12486 15875 19791 |
| 5111 15018 15980 | 8046 14636 17491 |
| 4989 10681 12810 | 2120 4643 13206 |
| 3763 10715 16515 | 6186 9675 12601 |
| 2259 10080 15642 | 784 5770 21585 |
| 9032 11319 21305 | |
| 3915 15213 20884 | |
| 11150 15022 20201 | |
| 1147 6749 19625 | |
| 12139 12939 18870 | |
| 3840 4634 10244 | |
| 1018 10231 17720 | |
| 2708 13056 13393 | |
| 5781 11588 18888 | |
| 1345 2036 5252 | |
| 5908 8143 15141 | |
| 1804 13693 18640 | |
| 10433 13965 16950 | |
| 9568 10122 15945 | |
| 547 6722 14015 | |
| 321 12844 14095 | |
| 2632 10513 14936 | |
| 6369 11995 20321 | |
| 9920 19136 21529 | |
| 1990 2726 10183 | |
| 5763 12118 15467 | |
| 503 10006 19564 | |
| 9839 11942 19472 | |
| 11205 13552 15389 | |
| 8841 13797 19697 | |
| 124 6053 18224 | |
| 6477 14406 21146 | |
| 1224 8027 16011 | |
| 3046 4422 17717 | |
| 739 12308 17760 | |
| 4014 4130 7835 | |
| 2266 5652 11981 | |
| 2711 7970 18317 | |
| 2196 15229 17217 | |
| 8636 13302 16764 | |
| 5612 15010 16657 | |

**Table A.1.10** Rate = 11/15 ($N_{inner}$ = 64800)

| | |
|---|---|
| 696 989 1238 3091 3116 3738 4269 6406 7033 8048 9157 10254 12033 16456 16912 | 16936 17122 17162 |
| 444 1488 6541 8626 10735 12447 13111 13706 14135 15195 15947 16453 16916 17137 17268 | 4868 8451 13183 |
| 401 460 992 1145 1576 1678 2238 2320 4280 6770 10027 12486 15363 16714 17157 | 3714 4451 16919 |
| 1161 3108 3727 4508 5092 5348 5582 7727 11793 12515 12917 13362 14247 16717 17205 | 11313 13801 17132 |
| 542 1190 6883 7911 8349 8835 10489 11631 14195 15009 15454 15482 16632 17040 17063 | 17070 17191 17242 |
| 17 487 776 880 5077 6172 9771 11446 12798 16016 16109 16171 17087 17132 17226 | 1911 11201 17186 |
| 1337 3275 3462 4229 9246 10180 10845 10866 12250 13633 14482 16024 16812 17186 17241 | 14 17190 17254 |
| 15 980 2305 3674 5971 8224 11499 11752 11770 12897 14082 14836 15311 16391 17209 | 11760 16008 16832 |
| 0 3926 5869 8696 9351 9391 11371 14052 14172 14636 14974 16619 16961 17033 17237 | 14543 17033 17278 |
| 3033 5317 6501 8579 10698 12168 12966 14019 15392 15806 15991 16493 16690 17062 17090 | 16129 16765 17155 |
| 981 1205 4400 6410 11003 13319 13405 14695 15846 16297 16492 16563 16616 16862 16953 | 6891 15561 17007 |
| 1725 4276 8869 9588 14062 14486 15474 15548 16300 16432 17042 17050 17060 17175 17273 | 12741 14744 17116 |
| 1807 5921 9960 10011 14305 14490 14872 15852 16054 16061 16306 16799 16833 17136 17262 | 8992 16661 17277 |
| 2826 4752 6017 6540 7016 8201 14245 14419 14716 15983 16569 16652 17171 17179 17247 | 1861 11130 16742 |
| 1662 2516 3345 5229 8086 9686 11456 12210 14595 15808 16011 16421 16825 17112 17195 | 4822 13331 16192 |
| 2890 4821 5987 7226 8823 9869 12468 14694 15352 15805 16075 16462 17102 17251 17263 | 13281 14027 14989 |
| 3751 3890 4382 5720 10281 10411 11350 12721 13121 14127 14980 15202 15335 16735 17123 | 38 14887 17141 |
| 26 30 2805 5457 6630 7188 7477 7556 11065 16608 16859 16909 16943 17030 17103 | 10698 13452 15674 |
| 40 4524 5043 5566 9645 10204 10282 11696 13080 14837 15607 16274 17034 17225 17266 | 4 2539 16877 |
| 904 3157 6284 7151 7984 11712 12887 13767 15547 16099 16753 16829 17044 17250 17259 | 857 17170 17249 |
| 7 311 4876 8334 9249 11267 14072 14559 15003 15235 15686 16331 17177 17238 17253 | 11449 11906 12867 |
| 4410 8066 8596 9631 10369 11249 12610 15769 16791 16960 17018 17037 17062 17165 17204 | 285 14118 16831 |
| 24 8261 9691 10138 11607 12782 12786 13424 13933 15262 15795 16476 17084 17193 17220 | 15191 17214 17242 |
| 88 11622 14705 15890 | 39 728 16915 |
| 304 2026 2638 6018 | 2469 12969 15579 |
| 1163 4268 11620 17232 | 16644 17151 17164 |
| 9701 11785 14463 17260 | 2592 8280 10448 |
| 4118 10952 12224 17006 | 9236 12431 17173 |
| 3647 10823 11521 12060 | 9064 16892 17233 |
| 1717 3753 9199 11642 | 4526 16146 17038 |
| 2187 14280 17220 | 31 2116 16083 |
| 14787 16903 17061 | 15837 16951 17031 |
| 381 3534 4294 | 5362 8382 16618 |
| 3149 6947 8323 | 6137 13199 17221 |
| 12562 16724 16881 | 2841 15068 17068 |
| 7289 9997 15306 | 24 3620 17003 |
| 5615 13152 17260 | 9880 15718 16764 |
| 5666 16926 17027 | 1784 10240 17209 |
| 4190 7798 16831 | 2731 10293 10846 |
| 4778 10629 17180 | 3121 8723 16598 |
| 10001 13884 15453 | 8563 15662 17088 |
| 6 2237 8203 | 13 1167 14676 |
| 7831 15144 15160 | 29 13850 15963 |
| 9186 17204 17243 | 3654 7553 8114 |
| 9435 17168 17237 | 23 4362 14865 |
| 42 5701 17159 | 4434 14741 16688 |
| 7812 14259 15715 | 8362 13901 17244 |
| 39 4513 6658 | 13687 16736 17232 |
| 38 9368 11273 | 46 4229 13394 |
| 1119 4785 17182 | 13169 16383 16972 |
| 5620 16521 16729 | 16031 16681 16952 |
| 16 6685 17242 | 3384 9894 12580 |
| 210 3452 12383 | 9841 14414 16165 |
| 466 14462 16250 | 5013 17099 17115 |
| 10548 12633 13962 | 2130 8941 17266 |
| 1452 6005 16453 | 6907 15428 17241 |
| 22 4120 13684 | 16 1860 17235 |
| 5195 11563 16522 | 2151 16014 16643 |
| 5518 16705 17201 | 14954 15958 17222 |
| 12233 14552 15471 | 3969 8419 15116 |
| 6067 13440 17248 | 31 15593 16984 |
| 8660 8967 17061 | 11514 16605 17255 |
| 8673 12176 15051 | |
| 5959 15767 16541 | |
| 3244 12109 12414 | |
| 31 15913 16323 | |
| 3270 15686 16653 | |
| 24 7346 14675 | |
| 12 1531 8740 | |
| 6228 7565 16667 | |

**Table A.1.11** Rate = 12/15 ($N_{inner}$ = 64800)

| | |
|---|---|
| 584 1472 1621 1867 3338 3568 3723 4185 5126 5889 7737 8632 8940 9725 | 4023 6108 6911 |
| 221 445 590 3779 3835 6939 7743 8280 8448 8491 9367 10042 11242 12917 | 8621 10184 11650 |
| 4662 4837 4900 5029 6449 6687 6751 8684 9936 11681 11811 11886 12089 12909 | 6726 10861 12348 |
| 2418 3018 3647 4210 4473 7447 7502 9490 10067 11092 11139 11256 12201 12383 | 3228 6302 7388 |
| 2591 2947 3349 3406 4417 4519 5176 6672 8498 8863 9201 11294 11376 12184 | 1 1137 5358 |
| 27 101 197 290 871 1727 3911 5411 6676 8701 9350 10310 10798 12439 | 381 2424 8537 |
| 1765 1897 2923 3584 3901 4048 6963 7054 7132 9165 10184 10824 11278 12669 | 3256 7508 10044 |
| 2183 3740 4808 5217 5660 6375 6787 8219 8466 9037 10353 10583 11118 12762 | 1980 2219 4569 |
| 73 1594 2146 2715 3501 3572 3639 3725 6959 7187 8406 10120 10507 10691 | 2468 5699 10319 |
| 240 732 1215 2185 2788 2830 3499 3881 4197 4991 6425 7061 9756 10491 | 2803 3314 12808 |
| 831 1568 1828 3424 4319 4516 4639 6018 9702 10203 10417 11240 11518 12458 | 8578 9642 11533 |
| 2024 2970 3048 3638 3676 4152 5284 5779 5926 9426 9945 10873 11787 11837 | 829 4585 7923 |
| 1049 1218 1651 2328 3493 4363 5750 6483 7613 8782 9738 9803 11744 11937 | 59 329 5575 |
| 1193 2060 2289 2964 3478 4592 4756 6709 7162 8231 8326 11140 11908 12243 | 1067 5709 6867 |
| 978 2120 2439 3338 3850 4589 6567 8745 9656 9708 10161 10542 10711 12639 | 1175 4744 12219 |
| 2403 2938 3117 3247 3711 5593 5844 5932 7801 10152 10226 11498 12162 12941 | 109 2518 6756 |
| 1781 2229 2276 2533 3582 3951 5279 5774 7930 9824 10920 11038 12340 12440 | 2105 10626 11153 |
| 289 384 1980 2230 3464 3873 5958 8656 8942 9006 10175 11425 11745 12530 | 5192 10696 10749 |
| 155 354 1090 1330 2002 2236 3559 3705 4922 5958 6576 8564 9972 12760 | 6260 7641 8233 |
| 303 876 2059 2142 5244 5330 6644 7576 8614 9598 10410 10718 11033 12957 | 2998 3094 11214 |
| 3449 3617 4408 4602 4727 6182 8835 8928 9372 9644 10237 10747 11655 12747 | 3398 6466 11494 |
| 811 2565 2820 8677 8974 9632 11069 11548 11839 12107 12411 12695 12812 12890 | 6574 10448 12160 |
| 972 4123 4943 6385 6449 7339 7477 8379 9177 9359 10074 11709 12552 12831 | 2734 10755 12780 |
| 842 973 1541 2262 2905 5276 6758 7099 7894 8128 8325 8663 8875 10050 | 1028 7958 10825 |
| 474 791 968 3902 4924 4965 5085 5908 6109 6329 7931 9038 9401 10568 | 8545 8602 10793 |
| 1397 4461 4658 5911 6037 7127 7318 8678 8924 9000 9473 9602 10446 12692 | 392 3398 11417 |
| 1334 7571 12881 | 6639 9291 12571 |
| 1393 1447 7972 | 1067 7919 8934 |
| 633 1257 10597 | 1064 2848 12753 |
| 4843 5102 11056 | 6076 8656 12690 |
| 3294 8015 10513 | 5504 6193 10171 |
| 1108 10374 10546 | 1951 7156 7356 |
| 5353 7824 10111 | 4389 4780 7889 |
| 3398 7674 8569 | 526 4804 9141 |
| 7719 9478 10503 | 1238 3648 10464 |
| 2997 9418 9581 | 2587 5624 12557 |
| 5777 6519 11229 | 5560 5903 11963 |
| 1966 5214 9899 | 1134 2570 3297 |
| 6 4088 5827 | 10041 11583 12157 |
| 836 9248 9612 | 1263 9585 12912 |
| 483 7229 7548 | 3744 7898 10646 |
| 7865 8289 9804 | 45 9074 10315 |
| 2915 11098 11900 | 1051 6188 10038 |
| 6180 7096 9481 | 2242 8394 12712 |
| 1431 6786 8924 | 3598 9025 12651 |
| 748 6757 8625 | 2295 3540 5610 |
| 3312 4475 7204 | 1914 4378 12423 |
| 1852 8958 11020 | 1766 3635 12759 |
| 1915 2903 4006 | 5177 9586 11143 |
| 6776 10886 12531 | 943 3590 11649 |
| 2594 9998 12742 | 4864 6905 10454 |
| 159 2002 12079 | 5852 6042 10421 |
| 853 3281 3762 | 6095 8285 12349 |
| 5201 5798 6413 | 2070 7171 8563 |
| 3882 6062 12047 | 718 12234 12716 |
| 4133 6775 9657 | 512 10667 11353 |
| 228 6874 11183 | 3629 6485 7040 |
| 7433 10728 10864 | 2880 8865 11466 |
| 7735 8073 12734 | 4490 10220 11796 |
| 2844 4621 11779 | 5440 8819 9103 |
| 3909 7103 12804 | 5262 7543 12411 |
| 6002 9704 11060 | 516 7779 10940 |
| 5864 6856 7681 | 2515 5843 9202 |
| 3652 5869 7605 | 4684 5994 10586 |
| 2546 2657 4461 | 573 2270 3324 |
| 2423 4203 9111 | 7870 8317 10322 |
| 244 1855 4691 | 6856 7638 12909 |
| 1106 2178 6371 | 1583 7669 10781 |
| 391 1617 10126 | 8141 9085 12555 |
| 250 9259 10603 | 3903 5485 9992 |
| 3435 4614 6924 | 4467 11998 12904 |
| 1742 8045 9529 | |
| 7667 8875 11451 | |

**Table A.1.12** Rate = 13/15 ($N_{inner}$ = 64800)

| | |
|---|---|
| 142 2307 2598 2650 4028 4434 5781 5881 6016 6323 6681 6698 8125 | 1704 2480 4181 |
| 2932 4928 5248 5256 5983 6773 6828 7789 8426 8494 8534 8539 8583 | 7338 7929 7990 |
| 899 3295 3833 5399 6820 7400 7753 7890 8109 8451 8529 8564 8602 | 2615 3905 7981 |
| 21 3060 4720 5429 5636 5927 6966 8110 8170 8247 8355 8365 8616 | 4298 4548 8296 |
| 20 1745 2838 3799 4380 4418 4646 5059 7343 8161 8302 8456 8631 | 8262 8319 8630 |
| 9 6274 6725 6792 7195 7333 8027 8186 8209 8273 8442 8548 8632 | 892 1893 8028 |
| 494 1365 2405 3799 5188 5291 7644 7926 8139 8458 8504 8594 8625 | 5694 7237 8595 |
| 192 574 1179 4387 4695 5089 5831 7673 7789 8298 8301 8612 8632 | 1487 5012 5810 |
| 11 20 1406 6111 6176 6256 6708 6834 7828 8232 8457 8495 8602 | 4335 8593 8624 |
| 6 2654 3554 4483 4966 5866 6795 8069 8249 8301 8497 8509 8623 | 3509 4531 5273 |
| 21 1144 2355 3124 6773 6805 6887 7742 7994 8358 8374 8580 8611 | 10 22 830 |
| 335 4473 4883 5528 6096 7543 7586 7921 8197 8319 8394 8489 8636 | 4161 5208 6280 |
| 2919 4331 4419 4735 6366 6393 6844 7193 8165 8205 8544 8586 8617 | 275 7063 8634 |
| 12 19 742 930 3009 4330 6213 6224 7292 7430 7792 7922 8137 | 4 2725 3113 |
| 710 1439 1588 2434 3516 5239 6248 6827 8230 8448 8515 8581 8619 | 2279 7403 8174 |
| 200 1075 1868 5581 7349 7642 7698 8037 8201 8210 8320 8391 8526 | 1637 3328 3930 |
| 3 2501 4252 5256 5292 5567 6136 6321 6430 6486 7571 8521 8636 | 2810 4939 5624 |
| 3062 4599 5885 6529 6616 7314 7319 7567 8024 8153 8302 8372 8598 | 3 1234 7687 |
| 105 381 1574 4351 5452 5603 5943 7467 7788 7933 8362 8513 8587 | 2799 7740 8616 |
| 787 1857 3386 3659 6550 7131 7965 8015 8040 8312 8484 8525 8537 | 22 7701 8636 |
| 15 1118 4226 5197 5575 5761 6762 7038 8260 8338 8444 8512 8568 | 4302 7857 7993 |
| 36 5216 5368 5616 6029 6591 8038 8067 8299 8351 8565 8578 8585 | 7477 7794 8592 |
| 1 23 4300 4530 5426 5532 5817 6967 7124 7979 8022 8270 8437 | 9 6111 8591 |
| 629 2133 4828 5475 5875 5890 7194 8042 8345 8385 8518 8598 8612 | 5 8606 8628 |
| 11 1065 3782 4237 4993 7104 7863 7904 8104 8228 8321 8383 8565 | 347 3497 4033 |
| 2131 2274 3168 3215 3220 5597 6347 7812 8238 8354 8527 8557 8614 | 1747 2613 8636 |
| 5600 6591 7491 7696 | 1827 5600 7042 |
| 1766 8281 8626 | 580 1822 6842 |
| 1725 2280 5120 | 232 7134 7783 |
| 1650 3445 7652 | 4629 5000 7231 |
| 4312 6911 8626 | 951 2806 4947 |
| 15 1013 5892 | 571 3474 8577 |
| 2263 2546 2979 | 2437 2496 7945 |
| 1545 5873 7406 | 23 5873 8162 |
| 67 726 3697 | 12 1168 7686 |
| 2860 6443 8542 | 8315 8540 8596 |
| 17 911 2820 | 1766 2506 4733 |
| 1561 4580 6052 | 929 1516 3338 |
| 79 5269 7134 | 21 1216 6555 |
| 22 2410 2424 | 782 1452 8617 |
| 3501 5642 8627 | 8 6083 6087 |
| 808 6950 8571 | 667 3240 4583 |
| 4099 6389 7482 | 4030 4661 5790 |
| 4023 5000 7833 | 559 7122 8553 |
| 5476 5765 7917 | 3202 4388 4909 |
| 1008 3194 7207 | 2533 3673 8594 |
| 20 495 5411 | 1991 3954 6206 |
| 1703 8388 8635 | 6835 7900 7980 |
| 6 4395 4921 | 189 5722 8573 |
| 200 2053 8206 | 2680 4928 4998 |
| 1089 5126 5562 | 243 2579 7735 |
| 10 4193 7720 | 4281 8132 8566 |
| 1967 2151 4608 | 7656 7671 8609 |
| 22 738 3513 | 1116 2291 4166 |
| 3385 5066 8152 | 21 388 8021 |
| 440 1118 8537 | 6 1123 8369 |
| 3429 6058 7716 | 311 4918 8511 |
| 5213 7519 8382 | 0 3248 6290 |
| 5564 8365 8620 | 13 6762 7172 |
| 43 3219 8603 | 4209 5632 7563 |
| 4 5409 5815 | 49 127 8074 |
| 5 6376 7654 | 581 1735 4075 |
| 4091 5724 5953 | 0 2235 5470 |
| 5348 6754 8613 | 2178 5820 6179 |
| 1634 6398 6632 | 16 3575 6054 |
| 72 2058 8605 | 1095 4564 6458 |
| 3497 5811 7579 | 9 1581 5953 |
| 3846 6743 8559 | 2537 6469 8552 |
| 15 5933 8629 | 14 3874 4844 |
| 2133 5859 7068 | 0 3269 3551 |
| 4151 4617 8566 | 2114 7372 7926 |
| 2960 8270 8410 | 1875 2388 4057 |
| 2059 3617 8210 | 3232 4042 6663 |
| 544 1441 6895 | 9 401 583 |
| 4043 7482 8592 | 13 4100 6584 |
| 294 2180 8524 | 2299 4190 4410 |
| 3058 8227 8373 | 21 3670 4979 |
| 364 5756 8617 | |
| 5383 8555 8619 | |

## A.2 LDPC CODE MATRICES ($N_{INNER}$ = 16200)

**Table A.2.1** Rate = 2/15 ($N_{inner}$ = 16200)

| |
|---|
| 2889 3122 3208 4324 5968 7241 13215 |
| 281 923 1077 5252 6099 10309 11114 |
| 727 2413 2676 6151 6796 8945 12528 |
| 2252 2322 3093 3329 8443 12170 13748 |
| 575 2489 2944 6577 8772 11253 11657 |
| 310 1461 2482 4643 4780 6936 11970 |
| 8691 9746 10794 13582 |
| 3717 6535 12470 12752 |
| 6011 6547 7020 11746 |
| 5309 6481 10244 13824 |
| 5327 8773 8824 13343 |
| 3506 3575 9915 13609 |
| 3393 7089 11048 12816 |
| 3651 4902 6118 12048 |
| 4210 10132 13375 13377 |

**Table A.2.2** Rate = 3/15 ($N_{inner}$ = 16200)

| |
|---|
| 8 372 841 4522 5253 7430 8542 9822 10550 11896 11988 |
| 80 255 667 1511 3549 5239 5422 5497 7157 7854 11267 |
| 257 406 792 2916 3072 3214 3638 4090 8175 8892 9003 |
| 80 150 346 1883 6838 7818 9482 10366 10514 11468 12341 |
| 32 100 978 3493 6751 7787 8496 10170 10318 10451 12561 |
| 504 803 856 2048 6775 7631 8110 8221 8371 9443 10990 |
| 152 283 696 1164 4514 4649 7260 7370 11925 11986 12092 |
| 127 1034 1044 1842 3184 3397 5931 7577 11898 12339 12689 |
| 107 513 979 3934 4374 4658 7286 7809 8830 10804 10893 |
| 2045 2499 7197 8887 9420 9922 10132 10540 10816 11876 |
| 2932 6241 7136 7835 8541 9403 9817 11679 12377 12810 |
| 2211 2288 3937 4310 5952 6597 9692 10445 11064 11272 |

**Table A.2.3** Rate = 4/15 ($N_{inner}$ = 16200)

| |
|---|
| 19 585 710 3241 3276 3648 6345 9224 9890 10841 |
| 181 494 894 2562 3201 4382 5130 5308 6493 10135 |
| 150 569 919 1427 2347 4475 7857 8904 9903 |
| 1005 1018 1025 2933 3280 3946 4049 4166 5209 |
| 420 554 778 6908 7959 8344 8462 10912 11099 |
| 231 506 859 4478 4957 7664 7731 7908 8980 |
| 179 537 979 3717 5092 6315 6883 9353 9935 |
| 147 205 830 3609 3720 4667 7441 10196 11809 |
| 60 1021 1061 1554 4918 5690 6184 7986 11296 |
| 145 719 768 2290 2919 7272 8561 9145 10233 |
| 388 590 852 1579 1698 1974 9747 10192 10255 |
| 231 343 485 1546 3155 4829 7710 10394 11336 |
| 4381 5398 5987 9123 10365 11018 11153 |
| 2381 5196 6613 6844 7357 8732 11082 |
| 1730 4599 5693 6318 7626 9231 10663 |

**Table A.2.4** Rate = 5/15 ($N_{inner}$ = 16200)

| |
|---|
| 69 244 706 5145 5994 6066 6763 6815 8509 |
| 257 541 618 3933 6188 7048 7484 8424 9104 |
| 69 500 536 1494 1669 7075 7553 8202 10305 |
| 11 189 340 2103 3199 6775 7471 7918 10530 |
| 333 400 434 1806 3264 5693 8534 9274 10344 |
| 111 129 260 3562 3676 3680 3809 5169 7308 8280 |
| 100 303 342 3133 3952 4226 4713 5053 5717 9931 |
| 83 87 374 828 2460 4943 6311 8657 9272 9571 |
| 114 166 325 2680 4698 7703 7886 8791 9978 10684 |
| 281 542 549 1671 3178 3955 7153 7432 9052 10219 |
| 202 271 608 3860 4173 4203 5169 6871 8113 9757 |
| 16 359 419 3333 4198 4737 6170 7987 9573 10095 |
| 235 244 584 4640 5007 5563 6029 6816 7678 9968 |
| 123 449 646 2460 3845 4161 6610 7245 7686 8651 |
| 136 231 468 835 2622 3292 5158 5294 6584 9926 |
| 3085 4683 8191 9027 9922 9928 10550 |
| 2462 3185 3976 4091 8089 8772 9342 |

**Table A.2.5** Rate = 6/15 ($N_{inner}$ = 16200)

| |
|---|
| 27 430 519 828 1897 1943 2513 2600 2640 3310 3415 4266 5044 5100 5328 5483 5928 6204 6392 6416 6602 7019 7415 7623 8112 8485 8724 8994 9445 9667 |
| 27 174 188 631 1172 1427 1779 2217 2270 2601 2813 3196 3582 3895 3908 3948 4463 4955 5120 5809 5988 6478 6604 7096 7673 7735 7795 8925 9613 9670 |
| 27 370 617 852 910 1030 1326 1521 1606 2118 2248 2909 3214 3413 3623 3742 3752 4317 4694 5300 5687 6039 6100 6232 6491 6621 6860 7304 8542 8634 |
| 990 1753 7635 8540 |
| 933 1415 5666 8745 |
| 27 6567 8707 9216 |
| 2341 8692 9580 9615 |
| 260 1092 5839 6080 |
| 352 3750 4847 7726 |
| 4610 6580 9506 9597 |
| 2512 2974 4814 9348 |
| 1461 4021 5060 7009 |
| 1796 2883 5553 8306 |
| 1249 5422 7057 |
| 3965 6968 9422 |
| 1498 2931 5092 |
| 27 1090 6215 |
| 26 4232 6354 |

**Table A.2.6** Rate = 7/15 ($N_{inner}$ = 16200)

| |
|---|
| 553 742 901 1327 1544 2179 2519 3131 3280 3603 3789 3792 4253 5340 5934 5962 6004 6698 7793 8001 8058 8126 8276 8559 |
| 503 590 598 1185 1266 1336 1806 2473 3021 3356 3490 3680 3936 4501 4659 5891 6132 6340 6602 7447 8007 8045 8059 8249 |
| 795 831 947 1330 1502 2041 2328 2513 2814 2829 4048 4802 6044 6109 6461 6777 6800 7099 7126 8095 8428 8519 8556 8610 |
| 601 787 899 1757 2259 2518 2783 2816 2823 2949 3396 4330 4494 4684 4700 4837 4881 4975 5130 5464 6554 6912 7094 8297 |
| 4229 5628 7917 7992 |
| 1506 3374 4174 5547 |
| 4275 5650 8208 8533 |
| 1504 1747 3433 6345 |
| 3659 6955 7575 7852 |
| 607 3002 4913 6453 |
| 3533 6860 7895 8048 |
| 4094 6366 8314 |
| 2206 4513 5411 |
| 32 3882 5149 |
| 389 3121 4626 |
| 1308 4419 6520 |
| 2092 2373 6849 |
| 1815 3679 7152 |
| 3582 3979 6948 |
| 1049 2135 3754 |
| 2276 4442 6591 |

**Table A.2.7** Rate = 8/15 ($N_{inner}$ = 16200)

| |
|---|
| 5 519 825 1871 2098 2478 2659 2820 3200 3294 3650 3804 3949 4426 4460 4503 4568 4590 4949 5219 5662 5738 5905 5911 6160 6404 6637 6708 6737 6814 7263 7412 |
| 81 391 1272 1633 2062 2882 3443 3503 3535 3908 4033 4163 4490 4929 5262 5399 5576 5768 5910 6331 6430 6844 6867 7201 7274 7290 7343 7350 7378 7387 7440 7554 |
| 105 975 3421 3480 4120 4444 5957 5971 6119 6617 6761 6810 7067 7353 |
| 6 138 485 1444 1512 2615 2990 3109 5604 6435 6513 6632 6704 7507 |
| 20 858 1051 2539 3049 5162 5308 6158 6391 6604 6744 7071 7195 7238 |
| 1140 5838 6203 6748 |
| 6282 6466 6481 6638 |
| 2346 2592 5436 7487 |
| 2219 3897 5896 7528 |
| 2897 6028 7018 |
| 1285 1863 5324 |
| 3075 6005 6466 |
| 5 6020 7551 |
| 2121 3751 7507 |
| 4027 5488 7542 |
| 2 6012 7011 |
| 3823 5531 5687 |
| 1379 2262 5297 |
| 1882 7498 7551 |
| 3749 4806 7227 |
| 2 2074 6898 |
| 17 616 7482 |
| 9 6823 7480 |
| 5195 5880 7559 |

**Table A.2.8** Rate = 9/15 ($N_{inner}$ = 16200)

| | |
|---|---|
| 212 255 540 967 1033 1517 1538 3124 3408 3800 4373 4864 4905 5163 5177 6186 | 300 1748 6245 |
| 275 660 1351 2211 2876 3063 3433 4088 4273 4544 4618 4632 5548 6101 6111 6136 | 2724 3276 5349 |
| 279 335 494 865 1662 1681 3414 3775 4252 4595 5272 5471 5796 5907 5986 6008 | 1433 6117 6448 |
| 345 352 3094 3188 4297 4338 4490 4865 5303 6477 | 485 663 4955 |
| 222 681 1218 3169 3850 4878 4954 5666 6001 6237 | 711 1132 4315 |
| 172 512 1536 1559 2179 2227 3334 4049 6464 | 177 3266 4339 |
| 716 934 1694 2890 3276 3608 4332 4468 5945 | 1171 4841 4982 |
| 1133 1593 1825 2571 3017 4251 5221 5639 5845 | 33 1584 3692 |
| 1076 1222 6465 | 2820 3485 4249 |
| 159 5064 6078 | 1716 2428 3125 |
| 374 4073 5357 | 250 2275 6338 |
| 2833 5526 5845 | 108 1719 4961 |
| 1594 3639 5419 | |
| 1028 1392 4239 | |
| 115 622 2175 | |

**Table A.2.9** Rate = 10/15 ($N_{inner}$ = 16200)

| |
|---|
| 352 747 894 1437 1688 1807 1883 2119 2159 3321 3400 3543 3588 3770 3821 4384 4470 4884 5012 5036 5084 5101 5271 5281 5353 |
| 505 915 1156 1269 1518 1650 2153 2256 2344 2465 2509 2867 2875 3007 3254 3519 3687 4331 4439 4532 4940 5011 5076 5113 5367 |
| 268 346 650 919 1260 4389 4653 4721 4838 5054 5157 5162 5275 5362 |
| 220 236 828 1590 1792 3259 3647 4276 4281 4325 4963 4974 5003 5037 |
| 381 737 1099 1409 2364 2955 3228 3341 3473 3985 4257 4730 5173 5242 |
| 88 771 1640 1737 1803 2408 2575 2974 3167 3464 3780 4501 4901 5047 |
| 749 1502 2201 3189 |
| 2873 3245 3427 |
| 2158 2605 3165 |
| 1 3438 3606 |
| 10 3019 5221 |
| 371 2901 2923 |
| 9 3935 4683 |
| 1937 3502 3735 |
| 507 3128 4994 |
| 25 3854 4550 |
| 1178 4737 5366 |
| 2 223 5304 |
| 1146 5175 5197 |
| 1816 2313 3649 |
| 740 1951 3844 |
| 1320 3703 4791 |
| 1754 2905 4058 |
| 7 917 5277 |
| 3048 3954 5396 |
| 4804 4824 5105 |
| 2812 3895 5226 |
| 0 5318 5358 |
| 1483 2324 4826 |
| 2266 4752 5387 |

**Table A.2.10** Rate = 11/15 ($N_{inner}$ = 16200)

| | |
|---|---|
| 49 719 784 794 968 2382 2685 2873 2974 2995 3540 4179 | 2732 4132 4318 |
| 272 281 374 1279 2034 2067 2112 3429 3613 3815 3838 4216 | 225 2335 3497 |
| 206 714 820 1800 1925 2147 2168 2769 2806 3253 3415 4311 | 600 2246 2658 |
| 62 159 166 605 1496 1711 2652 3016 3347 3517 3654 4113 | 1240 2790 3020 |
| 363 733 1118 2062 2613 2736 3143 3427 3664 4100 4157 4314 | 301 1097 3539 |
| 57 142 436 983 1364 2105 2113 3074 3639 3835 4164 4242 | 1222 1267 2594 |
| 870 921 950 1212 1861 2128 2707 2993 3730 3968 3983 4227 | 1364 2004 3603 |
| 185 2684 3263 | 1142 1185 2147 |
| 2035 2123 2913 | 564 1505 2086 |
| 883 2221 3521 | 697 991 2908 |
| 1344 1773 4132 | 1467 2073 3462 |
| 438 3178 3650 | 2574 2818 3637 |
| 543 756 1639 | 748 2577 2772 |
| 1057 2337 2898 | 1151 1419 4129 |
| 171 3298 3929 | 164 1238 3401 |
| 1626 2960 3503 | |
| 484 3050 3323 | |
| 2283 2336 4189 | |

**Table A.2.11** Rate = 12/15 ($N_{inner}$ = 16200)

| | |
|---|---|
| 3 394 1014 1214 1361 1477 1534 1660 1856 2745 2987 2991 3124 3155 | 1113 3007 3239 |
| 59 136 528 781 803 928 1293 1489 1944 2041 2200 2613 2690 2847 | 1753 2478 3127 |
| 155 245 311 621 1114 1269 1281 1783 1995 2047 2672 2803 2885 3014 | 0 509 1811 |
| 79 870 974 1326 1449 1531 2077 2317 2467 2627 2811 3083 3101 3132 | 1672 2646 2984 |
| 4 582 660 902 1048 1482 1697 1744 1928 2628 2699 2728 3045 3104 | 965 1462 3230 |
| 175 395 429 1027 1061 1068 1154 1168 1175 2147 2359 2376 2613 2682 | 3 1077 2917 |
| 1388 2241 3118 3148 | 1183 1316 1662 |
| 143 506 2067 3148 | 968 1593 3239 |
| 1594 2217 2705 | 64 1996 2226 |
| 398 988 2551 | 1442 2058 3181 |
| 1149 2588 2654 | 513 973 1058 |
| 678 2844 3115 | 1263 3185 3229 |
| 1508 1547 1954 | 681 1394 3017 |
| 1199 1267 1710 | 419 2853 3217 |
| 2589 3163 3207 | 3 2404 3175 |
| 1 2583 2974 | 2417 2792 2854 |
| 2766 2897 3166 | 1879 2940 3235 |
| 929 1823 2742 | 647 1704 3060 |

**Table A.2.12** Rate = 13/15 ($N_{inner}$ = 16200)

| | |
|---|---|
| 71 334 645 779 786 1124 1131 1267 1379 1554 1766 1798 1939 | 401 465 1040 |
| 6 183 364 506 512 922 972 981 1039 1121 1537 1840 2111 | 112 392 621 |
| 6 71 153 204 253 268 781 799 873 1118 1194 1661 2036 | 82 897 1950 |
| 6 247 353 581 921 940 1108 1146 1208 1268 1511 1527 1671 | 887 1962 2125 |
| 6 37 466 548 747 1142 1203 1271 1512 1516 1837 1904 2125 | 793 1088 2159 |
| 6 171 863 953 1025 1244 1378 1396 1723 1783 1816 1914 2121 | 723 919 1139 |
| 1268 1360 1647 1769 | 610 839 1302 |
| 6 458 1231 1414 | 218 1080 1816 |
| 183 535 1244 1277 | 627 1646 1749 |
| 107 360 498 1456 | 496 1165 1741 |
| 6 2007 2059 2120 | 916 1055 1662 |
| 1480 1523 1670 1927 | 182 722 945 |
| 139 573 711 1790 | 5 595 1674 |
| 6 1541 1889 2023 | |
| 6 374 957 1174 | |
| 287 423 872 1285 | |
| 6 1809 1918 | |
| 65 818 1396 | |
| 590 766 2107 | |
| 192 814 1843 | |
| 775 1163 1256 | |
| 42 735 1415 | |
| 334 1008 2055 | |
| 109 596 1785 | |
| 406 534 1852 | |
| 684 719 1543 | |

# *Annex B*: Bit Interleaver Sequences

## B.1 PERMUTATION SEQUENCES OF GROUP-WISE INTERLEAVING FOR $N_{INNER}$ = 64800 ($N_{GROUP}$ = 180)

**Table B.1.1** QPSK ($N_{inner}$ = 64800)

| Code Rate | Order of Group-Wise Interleaving π(j) (0 ≤ j < 180) | | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 |
| | 23 | 24 | 25 | 26 | 27 | 28 | 29 | 30 | 31 | 32 | 33 | 34 | 35 | 36 | 37 | 38 | 39 | 40 | 41 | 42 | 43 | 44 | 45 |
| | 46 | 47 | 48 | 49 | 50 | 51 | 52 | 53 | 54 | 55 | 56 | 57 | 58 | 59 | 60 | 61 | 62 | 63 | 64 | 65 | 66 | 67 | 68 |
| | 69 | 70 | 71 | 72 | 73 | 74 | 75 | 76 | 77 | 78 | 79 | 80 | 81 | 82 | 83 | 84 | 85 | 86 | 87 | 88 | 89 | 90 | 91 |
| | 92 | 93 | 94 | 95 | 96 | 97 | 98 | 99 | 100 | 101 | 102 | 103 | 104 | 105 | 106 | 107 | 108 | 109 | 110 | 111 | 112 | 113 | 114 |
| | 115 | 116 | 117 | 118 | 119 | 120 | 121 | 122 | 123 | 124 | 125 | 126 | 127 | 128 | 129 | 130 | 131 | 132 | 133 | 134 | 135 | 136 | 137 |
| | 138 | 139 | 140 | 141 | 142 | 143 | 144 | 145 | 146 | 147 | 148 | 149 | 150 | 151 | 152 | 153 | 154 | 155 | 156 | 157 | 158 | 159 | 160 |
| | 161 | 162 | 163 | 164 | 165 | 166 | 167 | 168 | 169 | 170 | 171 | 172 | 173 | 174 | 175 | 176 | 177 | 178 | 179 | | | | |
| 2/15 | 70 | 149 | 136 | 153 | 104 | 110 | 134 | 61 | 129 | 126 | 58 | 150 | 177 | 168 | 78 | 71 | 120 | 60 | 155 | 175 | 9 | 161 | 103 |
| | 123 | 91 | 173 | 57 | 106 | 143 | 151 | 89 | 86 | 35 | 77 | 133 | 31 | 7 | 23 | 51 | 5 | 121 | 83 | 64 | 176 | 119 | 98 |
| | 49 | 130 | 128 | 79 | 162 | 32 | 172 | 87 | 131 | 45 | 114 | 93 | 96 | 39 | 68 | 105 | 85 | 109 | 13 | 33 | 145 | 18 | 12 |
| | 54 | 111 | 14 | 156 | 8 | 16 | 73 | 2 | 84 | 47 | 42 | 101 | 63 | 88 | 25 | 52 | 170 | 24 | 69 | 142 | 178 | 20 | 65 |
| | 97 | 66 | 80 | 11 | 59 | 19 | 115 | 154 | 26 | 147 | 28 | 50 | 160 | 102 | 55 | 139 | 125 | 116 | 138 | 167 | 53 | 169 | 165 |
| | 99 | 159 | 148 | 179 | 0 | 146 | 90 | 6 | 100 | 74 | 117 | 48 | 75 | 135 | 41 | 137 | 76 | 92 | 164 | 113 | 152 | 72 | 36 |
| | 3 | 163 | 15 | 46 | 21 | 44 | 108 | 34 | 56 | 140 | 127 | 158 | 94 | 67 | 122 | 1 | 27 | 171 | 30 | 157 | 112 | 81 | 118 |
| | 43 | 29 | 124 | 22 | 62 | 37 | 40 | 4 | 107 | 166 | 82 | 95 | 10 | 144 | 141 | 132 | 174 | 38 | 17 | | | | |
| 3/15 | 75 | 170 | 132 | 174 | 7 | 111 | 30 | 4 | 49 | 133 | 50 | 160 | 92 | 106 | 27 | 126 | 116 | 178 | 41 | 166 | 88 | 84 | 80 |
| | 153 | 103 | 51 | 58 | 107 | 167 | 39 | 108 | 24 | 145 | 96 | 74 | 65 | 8 | 40 | 76 | 140 | 44 | 68 | 125 | 119 | 82 | 53 |
| | 152 | 102 | 38 | 28 | 86 | 162 | 171 | 61 | 93 | 147 | 117 | 32 | 150 | 26 | 59 | 3 | 148 | 173 | 141 | 130 | 154 | 97 | 33 |
| | 172 | 115 | 118 | 127 | 6 | 16 | 0 | 143 | 9 | 100 | 67 | 98 | 110 | 2 | 169 | 47 | 83 | 164 | 155 | 123 | 159 | 42 | 105 |
| | 12 | 158 | 81 | 20 | 66 | 57 | 121 | 25 | 1 | 90 | 175 | 35 | 60 | 79 | 87 | 135 | 10 | 139 | 156 | 177 | 77 | 89 | 73 |
| | 113 | 52 | 109 | 134 | 36 | 176 | 54 | 69 | 146 | 31 | 15 | 71 | 18 | 95 | 124 | 85 | 14 | 78 | 129 | 161 | 19 | 72 | 13 |
| | 122 | 21 | 63 | 137 | 120 | 144 | 91 | 157 | 48 | 34 | 46 | 22 | 29 | 104 | 45 | 56 | 151 | 62 | 43 | 94 | 163 | 99 | 64 |
| | 138 | 101 | 23 | 11 | 17 | 136 | 128 | 114 | 112 | 165 | 5 | 142 | 179 | 37 | 70 | 131 | 55 | 168 | 149 | | | | |
| 4/15 | 141 | 86 | 22 | 20 | 176 | 21 | 37 | 82 | 6 | 122 | 130 | 40 | 62 | 44 | 24 | 117 | 8 | 145 | 36 | 79 | 172 | 149 | 127 |
| | 163 | 9 | 160 | 73 | 100 | 16 | 153 | 124 | 110 | 49 | 154 | 152 | 4 | 168 | 54 | 177 | 158 | 113 | 57 | 2 | 102 | 161 | 147 |
| | 18 | 103 | 1 | 41 | 104 | 144 | 39 | 105 | 131 | 77 | 69 | 108 | 159 | 61 | 45 | 156 | 0 | 83 | 157 | 119 | 112 | 118 | 92 |
| | 109 | 75 | 67 | 142 | 96 | 51 | 139 | 31 | 166 | 179 | 89 | 167 | 23 | 34 | 60 | 93 | 165 | 128 | 90 | 19 | 33 | 70 | 173 |
| | 174 | 129 | 55 | 98 | 88 | 97 | 146 | 123 | 84 | 111 | 132 | 71 | 140 | 136 | 10 | 115 | 63 | 46 | 42 | 50 | 138 | 81 | 59 |
| | 53 | 15 | 52 | 72 | 164 | 150 | 29 | 17 | 91 | 101 | 14 | 38 | 35 | 66 | 64 | 7 | 125 | 151 | 56 | 126 | 171 | 68 | 121 |
| | 28 | 65 | 106 | 78 | 47 | 143 | 12 | 169 | 120 | 27 | 74 | 48 | 133 | 43 | 116 | 137 | 94 | 3 | 25 | 134 | 13 | 107 | 162 |
| | 32 | 99 | 85 | 175 | 80 | 170 | 5 | 135 | 178 | 11 | 26 | 76 | 95 | 87 | 155 | 58 | 30 | 148 | 114 | | | | |
| 5/15 | 39 | 47 | 96 | 176 | 33 | 75 | 165 | 38 | 27 | 58 | 90 | 76 | 17 | 46 | 10 | 91 | 133 | 69 | 171 | 32 | 117 | 78 | 13 |
| | 146 | 101 | 36 | 0 | 138 | 25 | 77 | 122 | 49 | 14 | 125 | 140 | 93 | 130 | 2 | 104 | 102 | 128 | 4 | 111 | 151 | 84 | 167 |
| | 35 | 127 | 156 | 55 | 82 | 85 | 66 | 114 | 8 | 147 | 115 | 113 | 5 | 31 | 100 | 106 | 48 | 52 | 67 | 107 | 18 | 126 | 112 |
| | 50 | 9 | 143 | 28 | 160 | 71 | 79 | 43 | 98 | 86 | 94 | 64 | 3 | 166 | 105 | 103 | 118 | 63 | 51 | 139 | 172 | 141 | 175 |
| | 56 | 74 | 95 | 29 | 45 | 129 | 120 | 168 | 92 | 150 | 7 | 162 | 153 | 137 | 108 | 159 | 157 | 173 | 23 | 89 | 132 | 57 | 37 |
| | 70 | 134 | 40 | 21 | 149 | 80 | 1 | 121 | 59 | 110 | 142 | 152 | 15 | 154 | 145 | 12 | 170 | 54 | 155 | 99 | 22 | 123 | 72 |
| | 177 | 131 | 116 | 44 | 158 | 73 | 11 | 65 | 164 | 119 | 174 | 34 | 83 | 53 | 24 | 42 | 60 | 26 | 161 | 68 | 178 | 41 | 148 |
| | 109 | 87 | 144 | 135 | 20 | 62 | 81 | 169 | 124 | 6 | 19 | 30 | 163 | 61 | 179 | 136 | 97 | 16 | 88 | | | | |

| | | | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **6/15** | 0 | 14 | 19 | 21 | 2 | 11 | 22 | 9 | 8 | 7 | 16 | 3 | 26 | 24 | 27 | 80 | 100 | 121 | 107 | 31 | 36 | 42 | 46 |
| | 49 | 75 | 93 | 127 | 95 | 119 | 73 | 61 | 63 | 117 | 89 | 99 | 129 | 52 | 111 | 124 | 48 | 122 | 82 | 106 | 91 | 92 | 71 |
| | 103 | 102 | 81 | 113 | 101 | 97 | 33 | 115 | 59 | 112 | 90 | 51 | 126 | 85 | 123 | 40 | 83 | 53 | 69 | 70 | 132 | 134 | 136 |
| | 138 | 140 | 142 | 144 | 146 | 148 | 150 | 152 | 154 | 156 | 158 | 160 | 162 | 164 | 166 | 168 | 170 | 172 | 174 | 176 | 178 | 4 | 5 |
| | 10 | 12 | 20 | 6 | 18 | 13 | 17 | 15 | 1 | 29 | 28 | 23 | 25 | 67 | 116 | 66 | 104 | 44 | 50 | 47 | 84 | 76 | 65 |
| | 130 | 56 | 128 | 77 | 39 | 94 | 87 | 120 | 62 | 88 | 74 | 35 | 110 | 131 | 98 | 60 | 37 | 45 | 78 | 125 | 41 | 34 | 118 |
| | 38 | 72 | 108 | 58 | 43 | 109 | 57 | 105 | 68 | 86 | 79 | 96 | 32 | 114 | 64 | 55 | 30 | 54 | 133 | 135 | 137 | 139 | 141 |
| | 143 | 145 | 147 | 149 | 151 | 153 | 155 | 157 | 159 | 161 | 163 | 165 | 167 | 169 | 171 | 173 | 175 | 177 | 179 | | | | |
| **7/15** | 152 | 172 | 113 | 167 | 100 | 163 | 159 | 144 | 114 | 47 | 161 | 125 | 99 | 89 | 179 | 123 | 149 | 177 | 1 | 132 | 37 | 26 | 16 |
| | 57 | 166 | 81 | 133 | 112 | 33 | 151 | 117 | 83 | 52 | 178 | 85 | 124 | 143 | 28 | 59 | 130 | 31 | 157 | 170 | 44 | 61 | 102 |
| | 155 | 111 | 153 | 55 | 54 | 176 | 17 | 68 | 169 | 20 | 104 | 38 | 147 | 7 | 174 | 6 | 90 | 15 | 56 | 120 | 13 | 34 | 48 |
| | 122 | 110 | 154 | 76 | 64 | 75 | 84 | 162 | 77 | 103 | 156 | 128 | 150 | 87 | 27 | 42 | 3 | 23 | 96 | 171 | 145 | 91 | 24 |
| | 78 | 5 | 69 | 175 | 8 | 29 | 106 | 137 | 131 | 43 | 93 | 160 | 108 | 164 | 12 | 140 | 71 | 63 | 141 | 109 | 129 | 82 | 80 |
| | 173 | 105 | 9 | 66 | 65 | 92 | 32 | 41 | 72 | 74 | 4 | 36 | 94 | 67 | 158 | 10 | 88 | 142 | 45 | 126 | 2 | 86 | 118 |
| | 73 | 79 | 121 | 148 | 95 | 70 | 51 | 53 | 21 | 115 | 135 | 25 | 168 | 11 | 136 | 18 | 138 | 134 | 119 | 146 | 0 | 97 | 22 |
| | 165 | 40 | 19 | 60 | 46 | 14 | 49 | 139 | 58 | 101 | 39 | 116 | 127 | 30 | 98 | 50 | 107 | 35 | 62 | | | | |
| **8/15** | 0 | 2 | 4 | 6 | 8 | 10 | 12 | 14 | 16 | 18 | 20 | 22 | 24 | 26 | 28 | 30 | 32 | 34 | 36 | 38 | 40 | 42 | 44 |
| | 46 | 48 | 50 | 52 | 54 | 56 | 58 | 60 | 62 | 64 | 66 | 68 | 70 | 72 | 74 | 76 | 78 | 80 | 82 | 84 | 86 | 88 | 90 |
| | 92 | 94 | 96 | 98 | 100 | 102 | 104 | 106 | 108 | 110 | 112 | 114 | 116 | 118 | 120 | 122 | 124 | 126 | 128 | 130 | 132 | 134 | 136 |
| | 138 | 140 | 142 | 144 | 146 | 148 | 150 | 152 | 154 | 156 | 158 | 160 | 162 | 164 | 166 | 168 | 170 | 172 | 174 | 176 | 178 | 1 | 3 |
| | 5 | 7 | 9 | 11 | 13 | 15 | 17 | 19 | 21 | 23 | 25 | 27 | 29 | 31 | 33 | 35 | 37 | 39 | 41 | 43 | 45 | 47 | 49 |
| | 51 | 53 | 55 | 57 | 59 | 61 | 63 | 65 | 67 | 69 | 71 | 73 | 75 | 77 | 79 | 81 | 83 | 85 | 87 | 89 | 91 | 93 | 95 |
| | 97 | 99 | 101 | 103 | 105 | 107 | 109 | 111 | 113 | 115 | 117 | 119 | 121 | 123 | 125 | 127 | 129 | 131 | 133 | 135 | 137 | 139 | 141 |
| | 143 | 145 | 147 | 149 | 151 | 153 | 155 | 157 | 159 | 161 | 163 | 165 | 167 | 169 | 171 | 173 | 175 | 177 | 179 | | | | |
| **9/15** | 0 | 2 | 4 | 6 | 8 | 10 | 12 | 14 | 16 | 18 | 20 | 22 | 24 | 26 | 28 | 30 | 32 | 34 | 36 | 38 | 40 | 42 | 44 |
| | 46 | 48 | 50 | 52 | 54 | 56 | 58 | 60 | 62 | 64 | 66 | 68 | 70 | 72 | 74 | 76 | 78 | 80 | 82 | 84 | 86 | 88 | 90 |
| | 92 | 94 | 96 | 98 | 100 | 102 | 104 | 106 | 108 | 110 | 112 | 114 | 116 | 118 | 120 | 122 | 124 | 126 | 128 | 130 | 132 | 134 | 136 |
| | 138 | 140 | 142 | 144 | 146 | 148 | 150 | 152 | 154 | 156 | 158 | 160 | 162 | 164 | 166 | 168 | 170 | 172 | 174 | 176 | 178 | 1 | 3 |
| | 5 | 7 | 9 | 11 | 13 | 15 | 17 | 19 | 21 | 23 | 25 | 27 | 29 | 31 | 33 | 35 | 37 | 39 | 41 | 43 | 45 | 47 | 49 |
| | 51 | 53 | 55 | 57 | 59 | 61 | 63 | 65 | 67 | 69 | 71 | 73 | 75 | 77 | 79 | 81 | 83 | 85 | 87 | 89 | 91 | 93 | 95 |
| | 97 | 99 | 101 | 103 | 105 | 107 | 109 | 111 | 113 | 115 | 117 | 119 | 121 | 123 | 125 | 127 | 129 | 131 | 133 | 135 | 137 | 139 | 141 |
| | 143 | 145 | 147 | 149 | 151 | 153 | 155 | 157 | 159 | 161 | 163 | 165 | 167 | 169 | 171 | 173 | 175 | 177 | 179 | | | | |
| **10/15** | 0 | 2 | 4 | 6 | 8 | 10 | 12 | 14 | 16 | 18 | 20 | 22 | 24 | 26 | 28 | 30 | 32 | 34 | 36 | 38 | 40 | 42 | 44 |
| | 46 | 48 | 50 | 52 | 54 | 56 | 58 | 60 | 62 | 64 | 66 | 68 | 70 | 72 | 74 | 76 | 78 | 80 | 82 | 84 | 86 | 88 | 90 |
| | 92 | 94 | 96 | 98 | 100 | 102 | 104 | 106 | 108 | 110 | 112 | 114 | 116 | 118 | 120 | 122 | 124 | 126 | 128 | 130 | 132 | 134 | 136 |
| | 138 | 140 | 142 | 144 | 146 | 148 | 150 | 152 | 154 | 156 | 158 | 160 | 162 | 164 | 166 | 168 | 170 | 172 | 174 | 176 | 178 | 1 | 3 |
| | 5 | 7 | 9 | 11 | 13 | 15 | 17 | 19 | 21 | 23 | 25 | 27 | 29 | 31 | 33 | 35 | 37 | 39 | 41 | 43 | 45 | 47 | 49 |
| | 51 | 53 | 55 | 57 | 59 | 61 | 63 | 65 | 67 | 69 | 71 | 73 | 75 | 77 | 79 | 81 | 83 | 85 | 87 | 89 | 91 | 93 | 95 |
| | 97 | 99 | 101 | 103 | 105 | 107 | 109 | 111 | 113 | 115 | 117 | 119 | 121 | 123 | 125 | 127 | 129 | 131 | 133 | 135 | 137 | 139 | 141 |
| | 143 | 145 | 147 | 149 | 151 | 153 | 155 | 157 | 159 | 161 | 163 | 165 | 167 | 169 | 171 | 173 | 175 | 177 | 179 | | | | |
| **11/15** | 0 | 14 | 19 | 21 | 2 | 11 | 22 | 9 | 8 | 7 | 16 | 3 | 26 | 24 | 27 | 80 | 100 | 121 | 107 | 31 | 36 | 42 | 46 |
| | 49 | 75 | 93 | 127 | 95 | 119 | 73 | 61 | 63 | 117 | 89 | 99 | 129 | 52 | 111 | 124 | 48 | 122 | 82 | 106 | 91 | 92 | 71 |
| | 103 | 102 | 81 | 113 | 101 | 97 | 33 | 115 | 59 | 112 | 90 | 51 | 126 | 85 | 123 | 40 | 83 | 53 | 69 | 70 | 132 | 134 | 136 |
| | 138 | 140 | 142 | 144 | 146 | 148 | 150 | 152 | 154 | 156 | 158 | 160 | 162 | 164 | 166 | 168 | 170 | 172 | 174 | 176 | 178 | 4 | 5 |
| | 10 | 12 | 20 | 6 | 18 | 13 | 17 | 15 | 1 | 29 | 28 | 23 | 25 | 67 | 116 | 66 | 104 | 44 | 50 | 47 | 84 | 76 | 65 |
| | 130 | 56 | 128 | 77 | 39 | 94 | 87 | 120 | 62 | 88 | 74 | 35 | 110 | 131 | 98 | 60 | 37 | 45 | 78 | 125 | 41 | 34 | 118 |
| | 38 | 72 | 108 | 58 | 43 | 109 | 57 | 105 | 68 | 86 | 79 | 96 | 32 | 114 | 64 | 55 | 30 | 54 | 133 | 135 | 137 | 139 | 141 |
| | 143 | 145 | 147 | 149 | 151 | 153 | 155 | 157 | 159 | 161 | 163 | 165 | 167 | 169 | 171 | 173 | 175 | 177 | 179 | | | | |
| **12/15** | 0 | 2 | 4 | 6 | 8 | 10 | 12 | 14 | 16 | 18 | 20 | 22 | 24 | 26 | 28 | 30 | 32 | 34 | 36 | 38 | 40 | 42 | 44 |
| | 46 | 48 | 50 | 52 | 54 | 56 | 58 | 60 | 62 | 64 | 66 | 68 | 70 | 72 | 74 | 76 | 78 | 80 | 82 | 84 | 86 | 88 | 90 |
| | 92 | 94 | 96 | 98 | 100 | 102 | 104 | 106 | 108 | 110 | 112 | 114 | 116 | 118 | 120 | 122 | 124 | 126 | 128 | 130 | 132 | 134 | 136 |
| | 138 | 140 | 142 | 144 | 146 | 148 | 150 | 152 | 154 | 156 | 158 | 160 | 162 | 164 | 166 | 168 | 170 | 172 | 174 | 176 | 178 | 1 | 3 |
| | 5 | 7 | 9 | 11 | 13 | 15 | 17 | 19 | 21 | 23 | 25 | 27 | 29 | 31 | 33 | 35 | 37 | 39 | 41 | 43 | 45 | 47 | 49 |
| | 51 | 53 | 55 | 57 | 59 | 61 | 63 | 65 | 67 | 69 | 71 | 73 | 75 | 77 | 79 | 81 | 83 | 85 | 87 | 89 | 91 | 93 | 95 |
| | 97 | 99 | 101 | 103 | 105 | 107 | 109 | 111 | 113 | 115 | 117 | 119 | 121 | 123 | 125 | 127 | 129 | 131 | 133 | 135 | 137 | 139 | 141 |
| | 143 | 145 | 147 | 149 | 151 | 153 | 155 | 157 | 159 | 161 | 163 | 165 | 167 | 169 | 171 | 173 | 175 | 177 | 179 | | | | |

| | | | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **13/15** | 0 | 2 | 4 | 6 | 8 | 10 | 12 | 14 | 16 | 18 | 20 | 22 | 24 | 26 | 28 | 30 | 32 | 34 | 36 | 38 | 40 | 42 | 44 |
| | 46 | 48 | 50 | 52 | 54 | 56 | 58 | 60 | 62 | 64 | 66 | 68 | 70 | 72 | 74 | 76 | 78 | 80 | 82 | 84 | 86 | 88 | 90 |
| | 92 | 94 | 96 | 98 | 100 | 102 | 104 | 106 | 108 | 110 | 112 | 114 | 116 | 118 | 120 | 122 | 124 | 126 | 128 | 130 | 132 | 134 | 136 |
| | 138 | 140 | 142 | 144 | 146 | 148 | 150 | 152 | 154 | 156 | 158 | 160 | 162 | 164 | 166 | 168 | 170 | 172 | 174 | 176 | 178 | 1 | 3 |
| | 5 | 7 | 9 | 11 | 13 | 15 | 17 | 19 | 21 | 23 | 25 | 27 | 29 | 31 | 33 | 35 | 37 | 39 | 41 | 43 | 45 | 47 | 49 |
| | 51 | 53 | 55 | 57 | 59 | 61 | 63 | 65 | 67 | 69 | 71 | 73 | 75 | 77 | 79 | 81 | 83 | 85 | 87 | 89 | 91 | 93 | 95 |
| | 97 | 99 | 101 | 103 | 105 | 107 | 109 | 111 | 113 | 115 | 117 | 119 | 121 | 123 | 125 | 127 | 129 | 131 | 133 | 135 | 137 | 139 | 141 |
| | 143 | 145 | 147 | 149 | 151 | 153 | 155 | 157 | 159 | 161 | 163 | 165 | 167 | 169 | 171 | 173 | 175 | 177 | 179 | | | | |

**Table B.1.2** 16QAM ($N_{inner}$ = 64800)

| Code Rate | Order of Group-Wise Interleaving π(j) (0 ≤ j < 180) | | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 |
| | 23 | 24 | 25 | 26 | 27 | 28 | 29 | 30 | 31 | 32 | 33 | 34 | 35 | 36 | 37 | 38 | 39 | 40 | 41 | 42 | 43 | 44 | 45 |
| | 46 | 47 | 48 | 49 | 50 | 51 | 52 | 53 | 54 | 55 | 56 | 57 | 58 | 59 | 60 | 61 | 62 | 63 | 64 | 65 | 66 | 67 | 68 |
| | 69 | 70 | 71 | 72 | 73 | 74 | 75 | 76 | 77 | 78 | 79 | 80 | 81 | 82 | 83 | 84 | 85 | 86 | 87 | 88 | 89 | 90 | 91 |
| | 92 | 93 | 94 | 95 | 96 | 97 | 98 | 99 | 100 | 101 | 102 | 103 | 104 | 105 | 106 | 107 | 108 | 109 | 110 | 111 | 112 | 113 | 114 |
| | 115 | 116 | 117 | 118 | 119 | 120 | 121 | 122 | 123 | 124 | 125 | 126 | 127 | 128 | 129 | 130 | 131 | 132 | 133 | 134 | 135 | 136 | 137 |
| | 138 | 139 | 140 | 141 | 142 | 143 | 144 | 145 | 146 | 147 | 148 | 149 | 150 | 151 | 152 | 153 | 154 | 155 | 156 | 157 | 158 | 159 | 160 |
| | 161 | 162 | 163 | 164 | 165 | 166 | 167 | 168 | 169 | 170 | 171 | 172 | 173 | 174 | 175 | 176 | 177 | 178 | 179 | | | | |
| 2/15 | 5 | 58 | 29 | 154 | 125 | 34 | 0 | 169 | 80 | 59 | 13 | 42 | 77 | 167 | 32 | 87 | 24 | 92 | 124 | 143 | 114 | 120 | 166 |
| | 138 | 64 | 136 | 149 | 57 | 18 | 101 | 119 | 35 | 33 | 113 | 75 | 108 | 104 | 3 | 27 | 39 | 172 | 159 | 129 | 62 | 146 | 142 |
| | 19 | 147 | 111 | 70 | 74 | 79 | 10 | 132 | 1 | 161 | 155 | 90 | 15 | 133 | 47 | 112 | 84 | 28 | 160 | 117 | 150 | 49 | 7 |
| | 81 | 44 | 63 | 118 | 4 | 158 | 148 | 82 | 69 | 36 | 162 | 86 | 71 | 22 | 26 | 61 | 40 | 126 | 170 | 177 | 23 | 91 | 68 |
| | 56 | 110 | 21 | 93 | 107 | 85 | 20 | 128 | 109 | 66 | 83 | 12 | 179 | 141 | 97 | 78 | 157 | 72 | 130 | 99 | 165 | 45 | 11 |
| | 152 | 168 | 14 | 16 | 2 | 137 | 140 | 121 | 173 | 50 | 55 | 94 | 144 | 73 | 51 | 98 | 174 | 178 | 17 | 100 | 9 | 122 | 54 |
| | 38 | 156 | 131 | 127 | 164 | 102 | 116 | 176 | 30 | 37 | 139 | 95 | 43 | 135 | 53 | 89 | 106 | 171 | 76 | 175 | 153 | 96 | 151 |
| | 115 | 52 | 6 | 123 | 134 | 31 | 103 | 163 | 65 | 105 | 48 | 25 | 8 | 60 | 67 | 88 | 46 | 41 | 145 | | | | |
| 3/15 | 52 | 92 | 175 | 26 | 45 | 81 | 117 | 74 | 119 | 147 | 120 | 135 | 144 | 87 | 3 | 51 | 20 | 170 | 143 | 125 | 15 | 39 | 5 |
| | 174 | 79 | 16 | 176 | 44 | 19 | 69 | 11 | 111 | 121 | 37 | 160 | 88 | 50 | 76 | 129 | 138 | 157 | 86 | 113 | 164 | 142 | 98 |
| | 9 | 93 | 166 | 78 | 73 | 167 | 168 | 40 | 131 | 27 | 89 | 156 | 177 | 171 | 116 | 152 | 0 | 127 | 36 | 8 | 153 | 59 | 75 |
| | 13 | 105 | 55 | 122 | 132 | 172 | 2 | 58 | 126 | 162 | 30 | 77 | 158 | 17 | 96 | 100 | 42 | 63 | 134 | 154 | 6 | 90 | 128 |
| | 83 | 60 | 146 | 124 | 178 | 99 | 123 | 108 | 133 | 159 | 151 | 145 | 61 | 53 | 68 | 31 | 41 | 94 | 35 | 21 | 49 | 82 | 80 |
| | 4 | 155 | 7 | 57 | 95 | 62 | 56 | 65 | 140 | 163 | 148 | 23 | 161 | 169 | 47 | 67 | 139 | 72 | 43 | 110 | 46 | 150 | 109 |
| | 115 | 32 | 14 | 179 | 85 | 165 | 112 | 25 | 64 | 173 | 10 | 102 | 114 | 71 | 66 | 84 | 24 | 141 | 29 | 104 | 107 | 54 | 12 |
| | 91 | 1 | 118 | 136 | 18 | 101 | 149 | 130 | 103 | 106 | 38 | 70 | 48 | 28 | 137 | 97 | 34 | 22 | 33 | | | | |
| 4/15 | 165 | 8 | 136 | 2 | 58 | 30 | 127 | 64 | 38 | 164 | 123 | 45 | 78 | 17 | 47 | 105 | 159 | 134 | 124 | 147 | 148 | 109 | 67 |
| | 98 | 157 | 57 | 156 | 170 | 46 | 12 | 172 | 29 | 9 | 3 | 144 | 97 | 83 | 151 | 26 | 52 | 10 | 39 | 50 | 104 | 92 | 163 |
| | 72 | 125 | 36 | 14 | 55 | 48 | 1 | 149 | 33 | 110 | 6 | 130 | 140 | 89 | 77 | 22 | 171 | 139 | 112 | 113 | 152 | 16 | 7 |
| | 85 | 11 | 28 | 153 | 73 | 62 | 44 | 135 | 116 | 4 | 61 | 117 | 53 | 111 | 178 | 94 | 81 | 68 | 114 | 173 | 75 | 101 | 88 |
| | 65 | 99 | 126 | 141 | 43 | 15 | 18 | 90 | 35 | 24 | 142 | 25 | 120 | 19 | 154 | 0 | 174 | 93 | 167 | 150 | 107 | 86 | 129 |
| | 175 | 87 | 21 | 66 | 106 | 82 | 179 | 118 | 41 | 95 | 145 | 37 | 23 | 168 | 166 | 49 | 103 | 108 | 56 | 91 | 69 | 128 | 121 |
| | 96 | 133 | 100 | 161 | 143 | 119 | 102 | 59 | 20 | 40 | 70 | 79 | 80 | 51 | 13 | 177 | 131 | 132 | 176 | 155 | 31 | 63 | 5 |
| | 162 | 76 | 42 | 160 | 115 | 71 | 158 | 54 | 137 | 146 | 32 | 169 | 122 | 138 | 84 | 74 | 60 | 34 | 27 | | | | |
| 5/15 | 129 | 65 | 160 | 140 | 32 | 50 | 162 | 86 | 177 | 57 | 157 | 9 | 134 | 104 | 24 | 7 | 122 | 46 | 17 | 77 | 31 | 92 | 163 |
| | 148 | 133 | 99 | 18 | 0 | 167 | 101 | 110 | 135 | 124 | 71 | 107 | 5 | 123 | 69 | 108 | 141 | 179 | 96 | 113 | 83 | 176 | 52 |
| | 117 | 81 | 125 | 59 | 15 | 137 | 170 | 63 | 112 | 88 | 34 | 61 | 106 | 3 | 42 | 100 | 152 | 87 | 171 | 72 | 161 | 4 | 178 |
| | 64 | 150 | 10 | 128 | 49 | 26 | 75 | 41 | 102 | 28 | 2 | 168 | 93 | 156 | 12 | 38 | 45 | 151 | 142 | 44 | 66 | 25 | 139 |
| | 173 | 51 | 29 | 147 | 175 | 90 | 164 | 80 | 131 | 58 | 114 | 145 | 121 | 70 | 115 | 146 | 120 | 55 | 158 | 8 | 39 | 97 | 159 |
| | 138 | 33 | 47 | 116 | 79 | 174 | 74 | 21 | 6 | 130 | 54 | 109 | 76 | 35 | 98 | 155 | 144 | 36 | 94 | 23 | 78 | 165 | 56 |
| | 154 | 89 | 132 | 67 | 119 | 143 | 40 | 53 | 20 | 136 | 172 | 91 | 27 | 13 | 127 | 73 | 105 | 85 | 30 | 103 | 19 | 84 | 37 |
| | 48 | 153 | 11 | 166 | 60 | 111 | 14 | 169 | 95 | 118 | 1 | 126 | 68 | 22 | 149 | 43 | 62 | 16 | 82 | | | | |
| 6/15 | 55 | 146 | 83 | 52 | 62 | 176 | 160 | 68 | 53 | 56 | 81 | 97 | 79 | 113 | 163 | 61 | 58 | 69 | 133 | 108 | 66 | 71 | 86 |
| | 144 | 57 | 67 | 116 | 59 | 70 | 156 | 172 | 65 | 149 | 155 | 82 | 138 | 136 | 141 | 111 | 96 | 170 | 90 | 140 | 64 | 159 | 15 |
| | 14 | 37 | 54 | 44 | 63 | 43 | 18 | 47 | 7 | 25 | 34 | 29 | 30 | 26 | 39 | 16 | 41 | 45 | 36 | 0 | 23 | 32 | 28 |
| | 27 | 38 | 48 | 33 | 22 | 49 | 51 | 60 | 46 | 21 | 4 | 3 | 20 | 13 | 50 | 35 | 24 | 40 | 17 | 42 | 6 | 112 | 93 |
| | 127 | 101 | 94 | 115 | 105 | 31 | 19 | 177 | 74 | 10 | 145 | 162 | 102 | 120 | 126 | 95 | 73 | 152 | 129 | 174 | 125 | 72 | 128 |
| | 78 | 171 | 8 | 142 | 178 | 154 | 85 | 107 | 75 | 12 | 9 | 151 | 77 | 117 | 109 | 80 | 106 | 134 | 98 | 1 | 122 | 173 | 161 |
| | 150 | 110 | 175 | 166 | 131 | 119 | 103 | 139 | 148 | 157 | 114 | 147 | 87 | 158 | 121 | 164 | 104 | 89 | 179 | 123 | 118 | 99 | 88 |
| | 11 | 92 | 165 | 84 | 168 | 124 | 169 | 2 | 130 | 167 | 153 | 137 | 143 | 91 | 100 | 5 | 76 | 132 | 135 | | | | |
| 7/15 | 174 | 148 | 56 | 168 | 38 | 7 | 110 | 9 | 42 | 153 | 160 | 15 | 46 | 21 | 121 | 88 | 114 | 85 | 13 | 83 | 74 | 81 | 70 |
| | 27 | 119 | 118 | 144 | 31 | 80 | 109 | 73 | 141 | 93 | 45 | 16 | 77 | 108 | 57 | 36 | 78 | 124 | 79 | 169 | 143 | 6 | 58 |
| | 75 | 67 | 5 | 104 | 125 | 140 | 172 | 8 | 39 | 17 | 29 | 159 | 86 | 87 | 41 | 99 | 89 | 47 | 128 | 43 | 161 | 154 | 101 |
| | 163 | 116 | 94 | 120 | 71 | 158 | 145 | 37 | 112 | 68 | 95 | 1 | 113 | 64 | 72 | 90 | 92 | 35 | 167 | 44 | 149 | 66 | 28 |

| | | | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 82 | 178 | 176 | 152 | 23 | 115 | 130 | 98 | 123 | 102 | 24 | 129 | 150 | 34 | 136 | 171 | 54 | 107 | 2 | 3 | 60 | 69 | 10 |
| | 117 | 91 | 157 | 33 | 105 | 155 | 62 | 162 | 40 | 127 | 14 | 165 | 26 | 52 | 19 | 48 | 137 | 4 | 22 | 122 | 173 | 18 | 11 |
| | 111 | 106 | 76 | 53 | 61 | 147 | 97 | 175 | 32 | 59 | 166 | 179 | 135 | 177 | 103 | 100 | 139 | 50 | 146 | 134 | 133 | 96 | 49 |
| | 126 | 151 | 84 | 156 | 30 | 138 | 164 | 132 | 12 | 0 | 20 | 63 | 170 | 142 | 65 | 55 | 25 | 51 | 131 | | | | |
| **8/15** | 71 | 81 | 170 | 101 | 143 | 77 | 128 | 112 | 155 | 41 | 40 | 54 | 57 | 28 | 179 | 114 | 97 | 13 | 18 | 151 | 91 | 88 | 79 |
| | 92 | 137 | 27 | 122 | 107 | 135 | 82 | 125 | 103 | 74 | 36 | 9 | 93 | 0 | 86 | 63 | 158 | 148 | 25 | 167 | 116 | 70 | 43 |
| | 102 | 106 | 149 | 24 | 169 | 113 | 127 | 34 | 165 | 100 | 136 | 75 | 134 | 156 | 96 | 84 | 178 | 150 | 140 | 20 | 126 | 73 | 68 |
| | 130 | 121 | 48 | 53 | 22 | 129 | 99 | 11 | 33 | 124 | 157 | 161 | 29 | 123 | 160 | 55 | 26 | 168 | 98 | 67 | 15 | 7 | 94 |
| | 144 | 1 | 61 | 65 | 146 | 42 | 172 | 115 | 59 | 76 | 4 | 162 | 39 | 85 | 12 | 72 | 58 | 44 | 132 | 47 | 141 | 35 | 176 |
| | 104 | 139 | 80 | 6 | 95 | 87 | 90 | 173 | 163 | 69 | 32 | 8 | 154 | 145 | 23 | 177 | 111 | 60 | 38 | 171 | 62 | 46 | 21 |
| | 5 | 153 | 49 | 78 | 2 | 109 | 147 | 89 | 166 | 152 | 138 | 31 | 14 | 131 | 50 | 37 | 16 | 117 | 66 | 19 | 10 | 159 | 142 |
| | 105 | 3 | 164 | 51 | 83 | 174 | 108 | 52 | 17 | 64 | 119 | 45 | 133 | 175 | 110 | 56 | 30 | 120 | 118 | | | | |
| **9/15** | 23 | 89 | 10 | 142 | 19 | 41 | 1 | 146 | 68 | 87 | 9 | 51 | 114 | 92 | 121 | 69 | 107 | 97 | 166 | 162 | 55 | 174 | 126 |
| | 149 | 110 | 128 | 172 | 28 | 111 | 78 | 82 | 120 | 71 | 52 | 5 | 141 | 29 | 30 | 132 | 148 | 72 | 85 | 17 | 160 | 156 | 154 |
| | 131 | 164 | 65 | 76 | 125 | 50 | 16 | 130 | 129 | 143 | 133 | 98 | 0 | 42 | 63 | 83 | 173 | 49 | 74 | 43 | 8 | 147 | 61 |
| | 36 | 167 | 119 | 27 | 86 | 102 | 48 | 115 | 99 | 38 | 163 | 73 | 101 | 4 | 153 | 118 | 90 | 124 | 151 | 66 | 93 | 123 | 157 |
| | 24 | 44 | 168 | 80 | 15 | 39 | 178 | 45 | 21 | 37 | 11 | 136 | 113 | 77 | 122 | 158 | 64 | 81 | 6 | 60 | 54 | 35 | 13 |
| | 57 | 171 | 100 | 117 | 46 | 62 | 33 | 175 | 137 | 59 | 103 | 127 | 70 | 108 | 88 | 179 | 40 | 112 | 104 | 170 | 140 | 67 | 32 |
| | 105 | 159 | 26 | 96 | 169 | 135 | 109 | 47 | 177 | 56 | 116 | 79 | 106 | 150 | 25 | 94 | 134 | 152 | 22 | 84 | 176 | 139 | 20 |
| | 34 | 165 | 138 | 7 | 91 | 12 | 145 | 58 | 95 | 2 | 144 | 53 | 75 | 14 | 155 | 18 | 31 | 3 | 161 | | | | |
| **10/15** | 68 | 71 | 54 | 19 | 25 | 21 | 102 | 32 | 105 | 29 | 16 | 79 | 53 | 82 | 107 | 91 | 67 | 94 | 85 | 48 | 83 | 58 | 42 |
| | 57 | 28 | 76 | 31 | 26 | 96 | 65 | 119 | 114 | 109 | 9 | 125 | 81 | 43 | 103 | 93 | 70 | 46 | 89 | 112 | 61 | 45 | 66 |
| | 38 | 77 | 115 | 56 | 87 | 113 | 100 | 75 | 72 | 60 | 47 | 92 | 36 | 98 | 4 | 59 | 6 | 44 | 20 | 86 | 3 | 73 | 95 |
| | 104 | 8 | 34 | 0 | 84 | 111 | 35 | 30 | 64 | 55 | 80 | 40 | 97 | 101 | 2 | 69 | 63 | 74 | 62 | 118 | 110 | 159 | 18 |
| | 50 | 33 | 7 | 175 | 51 | 131 | 106 | 134 | 88 | 140 | 117 | 132 | 147 | 153 | 116 | 161 | 10 | 39 | 126 | 136 | 90 | 37 | 174 |
| | 41 | 158 | 5 | 120 | 12 | 52 | 99 | 146 | 144 | 78 | 155 | 128 | 165 | 141 | 179 | 150 | 157 | 171 | 143 | 108 | 170 | 22 | 49 |
| | 11 | 27 | 160 | 178 | 133 | 142 | 121 | 168 | 173 | 123 | 13 | 15 | 154 | 127 | 139 | 151 | 163 | 172 | 138 | 176 | 145 | 129 | 162 |
| | 152 | 177 | 137 | 149 | 167 | 1 | 14 | 169 | 124 | 148 | 164 | 130 | 17 | 156 | 122 | 23 | 166 | 135 | 24 | | | | |
| **11/15** | 21 | 11 | 12 | 9 | 0 | 6 | 24 | 25 | 85 | 103 | 118 | 122 | 71 | 101 | 41 | 93 | 55 | 73 | 100 | 40 | 106 | 119 | 45 |
| | 80 | 128 | 68 | 129 | 61 | 124 | 36 | 126 | 117 | 114 | 132 | 136 | 140 | 144 | 148 | 152 | 156 | 160 | 164 | 168 | 172 | 176 | 20 |
| | 18 | 10 | 13 | 16 | 8 | 26 | 27 | 54 | 111 | 52 | 44 | 87 | 113 | 115 | 58 | 116 | 49 | 77 | 95 | 86 | 30 | 78 | 81 |
| | 56 | 125 | 53 | 89 | 94 | 50 | 123 | 65 | 83 | 133 | 137 | 141 | 145 | 149 | 153 | 157 | 161 | 165 | 169 | 173 | 177 | 2 | 17 |
| | 1 | 4 | 7 | 15 | 29 | 82 | 32 | 102 | 76 | 121 | 92 | 130 | 127 | 62 | 107 | 38 | 46 | 43 | 110 | 75 | 104 | 70 | 91 |
| | 69 | 96 | 120 | 42 | 34 | 79 | 35 | 105 | 134 | 138 | 142 | 146 | 150 | 154 | 158 | 162 | 166 | 170 | 174 | 178 | 19 | 5 | 3 |
| | 14 | 22 | 28 | 23 | 109 | 51 | 108 | 131 | 33 | 84 | 88 | 64 | 63 | 59 | 57 | 97 | 98 | 48 | 31 | 99 | 37 | 72 | 39 |
| | 74 | 66 | 60 | 67 | 47 | 112 | 90 | 135 | 139 | 143 | 147 | 151 | 155 | 159 | 163 | 167 | 171 | 175 | 179 | | | | |
| **12/15** | 120 | 32 | 38 | 113 | 71 | 31 | 65 | 109 | 36 | 106 | 134 | 66 | 29 | 86 | 136 | 108 | 83 | 70 | 79 | 81 | 105 | 48 | 30 |
| | 125 | 107 | 44 | 99 | 75 | 64 | 78 | 51 | 95 | 88 | 49 | 60 | 54 | 122 | 140 | 137 | 89 | 74 | 129 | 82 | 164 | 59 | 3 |
| | 67 | 92 | 98 | 42 | 77 | 28 | 121 | 87 | 18 | 21 | 93 | 72 | 2 | 142 | 112 | 9 | 50 | 8 | 90 | 139 | 14 | 97 | 63 |
| | 85 | 104 | 124 | 52 | 20 | 118 | 34 | 5 | 94 | 41 | 68 | 80 | 110 | 12 | 133 | 131 | 53 | 116 | 123 | 96 | 61 | 111 | 33 |
| | 173 | 165 | 175 | 166 | 169 | 174 | 159 | 148 | 158 | 155 | 145 | 178 | 126 | 100 | 154 | 156 | 179 | 157 | 46 | 149 | 171 | 37 | 153 |
| | 163 | 152 | 146 | 177 | 103 | 160 | 147 | 76 | 172 | 144 | 150 | 132 | 176 | 168 | 167 | 162 | 170 | 138 | 151 | 161 | 40 | 26 | 130 |
| | 119 | 114 | 117 | 115 | 84 | 57 | 62 | 13 | 47 | 24 | 0 | 7 | 10 | 69 | 19 | 127 | 17 | 16 | 27 | 91 | 4 | 73 | 35 |
| | 102 | 15 | 55 | 23 | 25 | 11 | 56 | 45 | 58 | 128 | 43 | 135 | 1 | 143 | 141 | 6 | 22 | 101 | 39 | | | | |
| **13/15** | 0 | 4 | 8 | 12 | 16 | 20 | 24 | 28 | 32 | 36 | 40 | 44 | 48 | 52 | 56 | 60 | 64 | 68 | 72 | 76 | 80 | 84 | 88 |
| | 92 | 96 | 100 | 104 | 108 | 112 | 116 | 120 | 124 | 128 | 132 | 136 | 140 | 144 | 148 | 152 | 156 | 160 | 164 | 168 | 172 | 176 | 1 |
| | 5 | 9 | 13 | 17 | 21 | 25 | 29 | 33 | 37 | 41 | 45 | 49 | 53 | 57 | 61 | 65 | 69 | 73 | 77 | 81 | 85 | 89 | 93 |
| | 97 | 101 | 105 | 109 | 113 | 117 | 121 | 125 | 129 | 133 | 137 | 141 | 145 | 149 | 153 | 157 | 161 | 165 | 169 | 173 | 177 | 2 | 6 |
| | 10 | 14 | 18 | 22 | 26 | 30 | 34 | 38 | 42 | 46 | 50 | 54 | 58 | 62 | 66 | 70 | 74 | 78 | 82 | 86 | 90 | 94 | 98 |
| | 102 | 106 | 110 | 114 | 118 | 122 | 126 | 130 | 134 | 138 | 142 | 146 | 150 | 154 | 158 | 162 | 166 | 170 | 174 | 178 | 3 | 7 | 11 |
| | 15 | 19 | 23 | 27 | 31 | 35 | 39 | 43 | 47 | 51 | 55 | 59 | 63 | 67 | 71 | 75 | 79 | 83 | 87 | 91 | 95 | 99 | 103 |
| | 107 | 111 | 115 | 119 | 123 | 127 | 131 | 135 | 139 | 143 | 147 | 151 | 155 | 159 | 163 | 167 | 171 | 175 | 179 | | | | |

**Table B.1.3** 64QAM ($N_{inner}$ = 64800 bits)

| Code Rate | Order of Group-Wise Interleaving π(j) (0 ≤ j < 180) | | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 |
| | 23 | 24 | 25 | 26 | 27 | 28 | 29 | 30 | 31 | 32 | 33 | 34 | 35 | 36 | 37 | 38 | 39 | 40 | 41 | 42 | 43 | 44 | 45 |
| | 46 | 47 | 48 | 49 | 50 | 51 | 52 | 53 | 54 | 55 | 56 | 57 | 58 | 59 | 60 | 61 | 62 | 63 | 64 | 65 | 66 | 67 | 68 |
| | 69 | 70 | 71 | 72 | 73 | 74 | 75 | 76 | 77 | 78 | 79 | 80 | 81 | 82 | 83 | 84 | 85 | 86 | 87 | 88 | 89 | 90 | 91 |
| | 92 | 93 | 94 | 95 | 96 | 97 | 98 | 99 | 100 | 101 | 102 | 103 | 104 | 105 | 106 | 107 | 108 | 109 | 110 | 111 | 112 | 113 | 114 |
| | 115 | 116 | 117 | 118 | 119 | 120 | 121 | 122 | 123 | 124 | 125 | 126 | 127 | 128 | 129 | 130 | 131 | 132 | 133 | 134 | 135 | 136 | 137 |
| | 138 | 139 | 140 | 141 | 142 | 143 | 144 | 145 | 146 | 147 | 148 | 149 | 150 | 151 | 152 | 153 | 154 | 155 | 156 | 157 | 158 | 159 | 160 |
| | 161 | 162 | 163 | 164 | 165 | 166 | 167 | 168 | 169 | 170 | 171 | 172 | 173 | 174 | 175 | 176 | 177 | 178 | 179 | | | | |
| 2/15 | 57 | 149 | 83 | 142 | 29 | 20 | 30 | 52 | 5 | 100 | 156 | 22 | 130 | 167 | 121 | 126 | 137 | 158 | 132 | 82 | 138 | 128 | 89 |
| | 88 | 162 | 32 | 107 | 3 | 97 | 166 | 125 | 129 | 1 | 6 | 68 | 148 | 40 | 87 | 0 | 80 | 49 | 24 | 78 | 101 | 43 | 112 |
| | 75 | 172 | 23 | 154 | 12 | 146 | 19 | 135 | 48 | 170 | 123 | 147 | 95 | 91 | 13 | 35 | 127 | 61 | 60 | 139 | 44 | 59 | 55 |
| | 109 | 157 | 177 | 153 | 165 | 66 | 152 | 77 | 98 | 131 | 11 | 81 | 62 | 175 | 141 | 171 | 51 | 155 | 76 | 150 | 174 | 58 | 143 |
| | 37 | 63 | 31 | 41 | 140 | 118 | 94 | 27 | 10 | 70 | 56 | 93 | 176 | 124 | 151 | 106 | 46 | 163 | 179 | 4 | 18 | 144 | 178 |
| | 161 | 145 | 71 | 114 | 7 | 105 | 133 | 84 | 86 | 17 | 21 | 28 | 54 | 74 | 65 | 110 | 122 | 169 | 64 | 111 | 119 | 42 | 85 |
| | 73 | 8 | 116 | 79 | 120 | 69 | 53 | 115 | 67 | 104 | 16 | 173 | 92 | 15 | 159 | 134 | 99 | 96 | 117 | 38 | 9 | 26 | 164 |
| | 47 | 103 | 113 | 136 | 168 | 102 | 14 | 45 | 72 | 25 | 50 | 34 | 36 | 90 | 160 | 2 | 33 | 39 | 108 | | | | |
| 3/15 | 74 | 72 | 104 | 62 | 122 | 35 | 130 | 0 | 95 | 150 | 139 | 151 | 133 | 109 | 31 | 59 | 18 | 148 | 9 | 105 | 57 | 132 | 102 |
| | 100 | 115 | 101 | 7 | 21 | 141 | 30 | 8 | 1 | 93 | 92 | 163 | 108 | 52 | 159 | 24 | 89 | 117 | 88 | 178 | 113 | 98 | 179 |
| | 144 | 156 | 54 | 164 | 12 | 63 | 39 | 22 | 25 | 137 | 13 | 41 | 44 | 80 | 87 | 111 | 145 | 23 | 85 | 166 | 83 | 55 | 154 |
| | 20 | 84 | 58 | 26 | 126 | 170 | 103 | 11 | 33 | 172 | 155 | 116 | 169 | 142 | 70 | 161 | 47 | 3 | 162 | 77 | 19 | 28 | 97 |
| | 124 | 6 | 168 | 107 | 60 | 76 | 143 | 121 | 42 | 157 | 65 | 43 | 173 | 56 | 171 | 90 | 131 | 119 | 94 | 5 | 68 | 138 | 149 |
| | 73 | 67 | 53 | 61 | 4 | 86 | 99 | 75 | 36 | 15 | 48 | 177 | 167 | 174 | 51 | 176 | 81 | 120 | 158 | 123 | 34 | 49 | 128 |
| | 10 | 134 | 147 | 96 | 160 | 50 | 146 | 16 | 38 | 78 | 91 | 152 | 46 | 127 | 27 | 175 | 135 | 79 | 125 | 82 | 2 | 129 | 153 |
| | 14 | 40 | 32 | 114 | 106 | 17 | 110 | 140 | 71 | 136 | 112 | 45 | 64 | 29 | 69 | 118 | 66 | 37 | 165 | | | | |
| 4/15 | 141 | 80 | 47 | 89 | 44 | 7 | 46 | 11 | 175 | 173 | 99 | 2 | 155 | 52 | 86 | 128 | 174 | 33 | 170 | 31 | 35 | 162 | 64 |
| | 95 | 92 | 4 | 16 | 49 | 137 | 104 | 29 | 9 | 60 | 167 | 50 | 23 | 43 | 176 | 121 | 71 | 132 | 103 | 144 | 39 | 12 | 90 |
| | 114 | 131 | 106 | 76 | 118 | 66 | 24 | 58 | 122 | 150 | 57 | 149 | 93 | 53 | 14 | 73 | 165 | 82 | 126 | 97 | 59 | 133 | 154 |
| | 153 | 72 | 36 | 5 | 96 | 120 | 134 | 101 | 61 | 115 | 0 | 28 | 42 | 18 | 145 | 156 | 85 | 146 | 6 | 161 | 10 | 22 | 138 |
| | 127 | 151 | 87 | 54 | 20 | 139 | 140 | 152 | 13 | 91 | 111 | 25 | 123 | 77 | 78 | 69 | 3 | 177 | 41 | 81 | 19 | 107 | 45 |
| | 148 | 70 | 160 | 51 | 21 | 116 | 48 | 157 | 17 | 125 | 142 | 83 | 110 | 37 | 98 | 179 | 129 | 168 | 172 | 1 | 40 | 166 | 159 |
| | 147 | 56 | 100 | 63 | 26 | 169 | 135 | 15 | 75 | 84 | 163 | 79 | 143 | 113 | 94 | 74 | 102 | 30 | 38 | 178 | 68 | 108 | 136 |
| | 105 | 158 | 117 | 34 | 109 | 67 | 62 | 32 | 119 | 124 | 171 | 8 | 55 | 65 | 130 | 88 | 112 | 27 | 164 | | | | |
| 5/15 | 166 | 54 | 6 | 27 | 141 | 134 | 58 | 46 | 55 | 91 | 56 | 100 | 172 | 80 | 18 | 152 | 12 | 108 | 170 | 29 | 144 | 147 | 106 |
| | 165 | 17 | 127 | 57 | 88 | 35 | 72 | 5 | 63 | 118 | 1 | 85 | 77 | 61 | 62 | 84 | 159 | 92 | 102 | 98 | 177 | 132 | 139 |
| | 59 | 149 | 11 | 8 | 154 | 129 | 33 | 15 | 143 | 4 | 95 | 101 | 53 | 42 | 40 | 9 | 111 | 130 | 123 | 82 | 81 | 114 | 119 |
| | 175 | 157 | 41 | 38 | 128 | 161 | 52 | 142 | 7 | 26 | 145 | 2 | 68 | 28 | 126 | 121 | 70 | 16 | 65 | 83 | 125 | 50 | 79 |
| | 37 | 74 | 164 | 168 | 160 | 122 | 60 | 32 | 24 | 138 | 75 | 69 | 0 | 36 | 97 | 117 | 14 | 109 | 173 | 120 | 112 | 87 | 176 |
| | 124 | 151 | 67 | 13 | 94 | 105 | 133 | 64 | 76 | 153 | 31 | 136 | 140 | 150 | 39 | 96 | 66 | 3 | 115 | 20 | 99 | 171 | 49 |
| | 25 | 45 | 22 | 30 | 156 | 158 | 163 | 135 | 21 | 146 | 90 | 169 | 78 | 93 | 178 | 116 | 19 | 155 | 110 | 73 | 104 | 167 | 44 |
| | 113 | 162 | 89 | 47 | 43 | 86 | 48 | 107 | 71 | 137 | 51 | 174 | 103 | 131 | 179 | 148 | 10 | 23 | 34 | | | | |
| 6/15 | 29 | 17 | 38 | 37 | 27 | 43 | 31 | 35 | 16 | 46 | 44 | 9 | 23 | 1 | 34 | 45 | 14 | 18 | 156 | 19 | 22 | 40 | 50 |
| | 24 | 56 | 49 | 26 | 42 | 69 | 47 | 59 | 61 | 66 | 52 | 64 | 65 | 67 | 54 | 170 | 68 | 132 | 51 | 70 | 41 | 21 | 5 |
| | 160 | 7 | 13 | 55 | 62 | 53 | 63 | 58 | 3 | 167 | 71 | 57 | 151 | 60 | 36 | 25 | 74 | 39 | 32 | 72 | 85 | 86 | 107 |
| | 113 | 48 | 88 | 2 | 129 | 137 | 20 | 73 | 166 | 75 | 77 | 142 | 174 | 15 | 149 | 28 | 145 | 92 | 169 | 30 | 133 | 163 | 119 |
| | 82 | 176 | 152 | 134 | 139 | 148 | 164 | 99 | 173 | 104 | 83 | 106 | 112 | 135 | 153 | 0 | 128 | 144 | 98 | 171 | 94 | 97 | 143 |
| | 110 | 118 | 127 | 84 | 79 | 108 | 126 | 131 | 93 | 111 | 91 | 4 | 125 | 162 | 157 | 158 | 109 | 140 | 123 | 154 | 150 | 80 | 11 |
| | 12 | 146 | 96 | 81 | 165 | 8 | 89 | 138 | 105 | 141 | 103 | 6 | 100 | 161 | 172 | 78 | 101 | 115 | 179 | 147 | 116 | 136 | 122 |
| | 87 | 33 | 130 | 124 | 175 | 120 | 90 | 102 | 10 | 114 | 159 | 76 | 177 | 178 | 121 | 168 | 95 | 117 | 155 | | | | |
| 7/15 | 103 | 36 | 155 | 175 | 52 | 130 | 16 | 178 | 141 | 86 | 49 | 129 | 73 | 84 | 142 | 177 | 110 | 8 | 96 | 77 | 139 | 167 | 109 |
| | 2 | 17 | 37 | 146 | 169 | 54 | 134 | 101 | 78 | 135 | 70 | 153 | 6 | 29 | 41 | 143 | 63 | 47 | 124 | 90 | 31 | 152 | 98 |
| | 59 | 133 | 15 | 79 | 164 | 67 | 50 | 128 | 23 | 34 | 154 | 69 | 45 | 9 | 27 | 35 | 156 | 170 | 113 | 127 | 102 | 82 | 149 |
| | 176 | 46 | 13 | 22 | 30 | 163 | 60 | 114 | 11 | 92 | 44 | 157 | 74 | 48 | 132 | 24 | 87 | 140 | 66 | 118 | 123 | 104 | 89 |

| | | | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 136 | 64 | 107 | 14 | 99 | 43 | 115 | 71 | 117 | 12 | 26 | 38 | 147 | 62 | 57 | 131 | 94 | 33 | 151 | 172 | 116 | 10 | 25 |
| | 75 | 144 | 179 | 51 | 120 | 20 | 80 | 160 | 174 | 106 | 1 | 21 | 88 | 137 | 61 | 105 | 5 | 18 | 32 | 158 | 72 | 56 | 125 |
| | 28 | 42 | 161 | 168 | 53 | 7 | 100 | 40 | 145 | 171 | 55 | 3 | 95 | 83 | 162 | 173 | 119 | 126 | 91 | 39 | 150 | 165 | 112 |
| | 122 | 93 | 76 | 138 | 166 | 108 | 121 | 97 | 81 | 148 | 65 | 111 | 4 | 19 | 85 | 159 | 68 | 58 | 0 | | | | |
| **8/15** | 86 | 71 | 51 | 48 | 89 | 94 | 46 | 81 | 67 | 49 | 80 | 37 | 55 | 61 | 36 | 57 | 52 | 92 | 60 | 82 | 76 | 72 | 44 |
| | 42 | 91 | 62 | 50 | 90 | 40 | 78 | 53 | 58 | 47 | 85 | 70 | 4 | 69 | 43 | 54 | 84 | 93 | 38 | 8 | 64 | 6 | 18 |
| | 77 | 95 | 66 | 59 | 83 | 73 | 17 | 87 | 3 | 75 | 65 | 88 | 79 | 14 | 151 | 117 | 32 | 22 | 123 | 30 | 33 | 162 | 144 |
| | 9 | 121 | 108 | 139 | 142 | 24 | 34 | 20 | 157 | 159 | 138 | 143 | 29 | 140 | 163 | 150 | 175 | 114 | 31 | 12 | 35 | 145 | 28 |
| | 27 | 26 | 16 | 98 | 102 | 103 | 133 | 161 | 21 | 25 | 107 | 153 | 45 | 156 | 23 | 125 | 141 | 56 | 166 | 5 | 1 | 170 | 119 |
| | 68 | 134 | 41 | 74 | 179 | 2 | 129 | 169 | 101 | 99 | 109 | 127 | 168 | 176 | 11 | 0 | 122 | 110 | 113 | 146 | 132 | 165 | 19 |
| | 13 | 39 | 7 | 164 | 106 | 172 | 154 | 149 | 10 | 173 | 131 | 167 | 63 | 147 | 155 | 100 | 171 | 158 | 160 | 15 | 178 | 148 | 152 |
| | 104 | 124 | 177 | 97 | 130 | 118 | 137 | 111 | 126 | 120 | 105 | 115 | 136 | 112 | 96 | 135 | 116 | 174 | 128 | | | | |
| **9/15** | 175 | 60 | 133 | 11 | 5 | 4 | 70 | 97 | 131 | 80 | 42 | 136 | 50 | 104 | 32 | 75 | 176 | 87 | 109 | 61 | 39 | 107 | 0 |
| | 172 | 23 | 90 | 54 | 160 | 48 | 173 | 27 | 100 | 129 | 14 | 7 | 142 | 20 | 103 | 38 | 126 | 157 | 144 | 21 | 64 | 44 | 79 |
| | 105 | 146 | 49 | 93 | 1 | 84 | 81 | 145 | 18 | 15 | 106 | 91 | 12 | 169 | 63 | 71 | 125 | 37 | 120 | 138 | 17 | 113 | 31 |
| | 130 | 140 | 8 | 25 | 74 | 134 | 115 | 9 | 171 | 46 | 68 | 33 | 116 | 2 | 179 | 52 | 92 | 36 | 78 | 164 | 177 | 24 | 72 |
| | 122 | 118 | 162 | 121 | 16 | 73 | 45 | 53 | 77 | 110 | 30 | 66 | 29 | 76 | 158 | 148 | 111 | 94 | 43 | 83 | 139 | 10 | 56 |
| | 98 | 114 | 117 | 152 | 174 | 47 | 62 | 128 | 85 | 155 | 178 | 26 | 96 | 41 | 82 | 150 | 143 | 58 | 69 | 127 | 86 | 13 | 141 |
| | 35 | 101 | 149 | 108 | 3 | 154 | 51 | 95 | 132 | 135 | 163 | 137 | 28 | 102 | 123 | 112 | 151 | 167 | 59 | 19 | 156 | 119 | 153 |
| | 168 | 55 | 65 | 34 | 6 | 159 | 170 | 57 | 67 | 40 | 89 | 147 | 165 | 22 | 99 | 124 | 88 | 161 | 166 | | | | |
| **10/15** | 16 | 163 | 92 | 56 | 111 | 141 | 65 | 118 | 78 | 55 | 5 | 148 | 19 | 153 | 75 | 128 | 32 | 178 | 22 | 156 | 99 | 124 | 4 |
| | 168 | 20 | 115 | 87 | 122 | 9 | 166 | 27 | 155 | 94 | 134 | 38 | 137 | 67 | 161 | 90 | 127 | 43 | 171 | 64 | 162 | 98 | 133 |
| | 34 | 138 | 73 | 154 | 100 | 58 | 103 | 169 | 23 | 117 | 88 | 50 | 13 | 175 | 68 | 39 | 102 | 54 | 37 | 149 | 29 | 150 | 104 |
| | 59 | 3 | 139 | 69 | 110 | 77 | 131 | 42 | 142 | 25 | 158 | 80 | 47 | 35 | 143 | 72 | 151 | 84 | 57 | 8 | 176 | 61 | 46 |
| | 41 | 51 | 10 | 173 | 63 | 107 | 125 | 48 | 11 | 177 | 24 | 30 | 91 | 76 | 109 | 140 | 74 | 114 | 82 | 120 | 1 | 79 | 66 |
| | 119 | 93 | 159 | 36 | 174 | 26 | 112 | 101 | 123 | 44 | 145 | 60 | 157 | 97 | 45 | 33 | 167 | 70 | 152 | 85 | 126 | 40 | 135 |
| | 62 | 108 | 95 | 49 | 31 | 147 | 71 | 113 | 89 | 132 | 6 | 144 | 18 | 105 | 83 | 130 | 2 | 172 | 17 | 164 | 81 | 52 | 7 |
| | 179 | 28 | 160 | 136 | 121 | 14 | 146 | 15 | 106 | 86 | 129 | 12 | 170 | 21 | 116 | 96 | 53 | 0 | 165 | | | | |
| **11/15** | 12 | 15 | 2 | 16 | 27 | 50 | 35 | 74 | 38 | 70 | 108 | 32 | 112 | 54 | 30 | 122 | 72 | 116 | 36 | 90 | 49 | 85 | 132 |
| | 138 | 144 | 150 | 156 | 162 | 168 | 174 | 0 | 14 | 9 | 5 | 23 | 66 | 68 | 52 | 96 | 117 | 84 | 128 | 100 | 63 | 60 | 127 |
| | 81 | 99 | 53 | 55 | 103 | 95 | 133 | 139 | 145 | 151 | 157 | 163 | 169 | 175 | 10 | 22 | 13 | 11 | 28 | 104 | 37 | 57 | 115 |
| | 46 | 65 | 129 | 107 | 75 | 119 | 110 | 31 | 43 | 97 | 78 | 125 | 58 | 134 | 140 | 146 | 152 | 158 | 164 | 170 | 176 | 4 | 19 |
| | 6 | 8 | 24 | 44 | 101 | 94 | 118 | 130 | 69 | 71 | 83 | 34 | 86 | 124 | 48 | 106 | 89 | 40 | 102 | 91 | 135 | 141 | 147 |
| | 153 | 159 | 165 | 171 | 177 | 3 | 20 | 7 | 17 | 25 | 87 | 41 | 120 | 47 | 80 | 59 | 62 | 88 | 45 | 56 | 131 | 61 | 126 |
| | 113 | 92 | 51 | 98 | 136 | 142 | 148 | 154 | 160 | 166 | 172 | 178 | 21 | 18 | 1 | 26 | 29 | 39 | 73 | 121 | 105 | 77 | 42 |
| | 114 | 93 | 82 | 111 | 109 | 67 | 79 | 123 | 64 | 76 | 33 | 137 | 143 | 149 | 155 | 161 | 167 | 173 | 179 | | | | |
| **12/15** | 83 | 93 | 94 | 47 | 55 | 40 | 38 | 77 | 110 | 124 | 87 | 61 | 102 | 76 | 33 | 35 | 92 | 59 | 74 | 11 | 138 | 72 | 67 |
| | 37 | 10 | 95 | 139 | 131 | 44 | 57 | 97 | 53 | 142 | 0 | 136 | 9 | 143 | 86 | 100 | 21 | 15 | 75 | 62 | 19 | 65 | 129 |
| | 101 | 79 | 22 | 68 | 73 | 23 | 18 | 81 | 98 | 112 | 8 | 128 | 103 | 25 | 43 | 126 | 54 | 90 | 28 | 109 | 46 | 91 | 41 |
| | 82 | 113 | 134 | 52 | 105 | 78 | 27 | 135 | 96 | 56 | 140 | 64 | 66 | 89 | 34 | 120 | 108 | 63 | 45 | 69 | 121 | 88 | 39 |
| | 29 | 133 | 106 | 117 | 127 | 32 | 42 | 58 | 71 | 118 | 51 | 84 | 85 | 80 | 104 | 132 | 111 | 30 | 26 | 48 | 50 | 31 | 141 |
| | 116 | 123 | 114 | 70 | 107 | 178 | 145 | 173 | 36 | 144 | 130 | 176 | 171 | 175 | 125 | 99 | 162 | 159 | 20 | 164 | 115 | 169 | 172 |
| | 165 | 161 | 151 | 119 | 122 | 152 | 157 | 4 | 137 | 148 | 153 | 170 | 154 | 166 | 13 | 150 | 16 | 167 | 174 | 163 | 49 | 6 | 168 |
| | 147 | 146 | 1 | 149 | 158 | 179 | 12 | 5 | 160 | 177 | 60 | 24 | 156 | 7 | 155 | 17 | 3 | 2 | 14 | | | | |
| **13/15** | 146 | 91 | 63 | 144 | 46 | 12 | 58 | 137 | 25 | 79 | 70 | 33 | 134 | 148 | 66 | 38 | 163 | 118 | 139 | 130 | 72 | 92 | 160 |
| | 23 | 133 | 153 | 128 | 86 | 152 | 106 | 53 | 93 | 61 | 5 | 158 | 172 | 121 | 135 | 44 | 149 | 168 | 0 | 124 | 143 | 27 | 30 |
| | 151 | 114 | 113 | 43 | 138 | 89 | 159 | 17 | 120 | 136 | 102 | 81 | 170 | 176 | 142 | 104 | 21 | 78 | 155 | 8 | 52 | 95 | 62 |
| | 40 | 174 | 6 | 131 | 48 | 18 | 1 | 179 | 34 | 123 | 77 | 26 | 84 | 157 | 85 | 56 | 147 | 67 | 76 | 162 | 10 | 51 | 103 |
| | 140 | 87 | 175 | 115 | 4 | 101 | 69 | 80 | 169 | 75 | 49 | 97 | 154 | 83 | 14 | 2 | 132 | 96 | 16 | 37 | 166 | 109 | 54 |
| | 42 | 28 | 32 | 171 | 119 | 55 | 94 | 65 | 20 | 165 | 3 | 47 | 90 | 117 | 88 | 177 | 11 | 59 | 68 | 73 | 41 | 150 | 111 |
| | 127 | 100 | 110 | 31 | 167 | 13 | 122 | 145 | 71 | 22 | 173 | 116 | 126 | 141 | 29 | 39 | 178 | 57 | 125 | 36 | 19 | 7 | 156 |
| | 107 | 9 | 98 | 74 | 45 | 161 | 112 | 50 | 99 | 24 | 35 | 164 | 64 | 129 | 15 | 60 | 82 | 108 | 105 | | | | |

**Table B.1.4** 256QAM ($N_{inner}$ = 64800)

| Code Rate | Order of Group-Wise Interleaving π(j) (0 ≤ j < 180) | | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 |
| | 23 | 24 | 25 | 26 | 27 | 28 | 29 | 30 | 31 | 32 | 33 | 34 | 35 | 36 | 37 | 38 | 39 | 40 | 41 | 42 | 43 | 44 | 45 |
| | 46 | 47 | 48 | 49 | 50 | 51 | 52 | 53 | 54 | 55 | 56 | 57 | 58 | 59 | 60 | 61 | 62 | 63 | 64 | 65 | 66 | 67 | 68 |
| | 69 | 70 | 71 | 72 | 73 | 74 | 75 | 76 | 77 | 78 | 79 | 80 | 81 | 82 | 83 | 84 | 85 | 86 | 87 | 88 | 89 | 90 | 91 |
| | 92 | 93 | 94 | 95 | 96 | 97 | 98 | 99 | 100 | 101 | 102 | 103 | 104 | 105 | 106 | 107 | 108 | 109 | 110 | 111 | 112 | 113 | 114 |
| | 115 | 116 | 117 | 118 | 119 | 120 | 121 | 122 | 123 | 124 | 125 | 126 | 127 | 128 | 129 | 130 | 131 | 132 | 133 | 134 | 135 | 136 | 137 |
| | 138 | 139 | 140 | 141 | 142 | 143 | 144 | 145 | 146 | 147 | 148 | 149 | 150 | 151 | 152 | 153 | 154 | 155 | 156 | 157 | 158 | 159 | 160 |
| | 161 | 162 | 163 | 164 | 165 | 166 | 167 | 168 | 169 | 170 | 171 | 172 | 173 | 174 | 175 | 176 | 177 | 178 | 179 | | | | |
| 2/15 | 112 | 78 | 104 | 6 | 59 | 80 | 49 | 120 | 114 | 27 | 113 | 3 | 109 | 44 | 69 | 164 | 91 | 137 | 39 | 31 | 21 | 127 | 151 |
| | 8 | 47 | 176 | 117 | 68 | 122 | 148 | 79 | 73 | 7 | 166 | 51 | 50 | 116 | 66 | 152 | 61 | 29 | 107 | 22 | 154 | 118 | 94 |
| | 24 | 35 | 55 | 38 | 88 | 54 | 2 | 15 | 19 | 67 | 101 | 74 | 169 | 138 | 41 | 162 | 175 | 136 | 62 | 161 | 121 | 163 | 115 |
| | 135 | 123 | 25 | 140 | 156 | 58 | 33 | 119 | 111 | 146 | 129 | 150 | 147 | 97 | 18 | 60 | 4 | 81 | 168 | 43 | 105 | 36 | 65 |
| | 13 | 5 | 108 | 145 | 23 | 70 | 20 | 173 | 159 | 100 | 128 | 172 | 170 | 1 | 37 | 83 | 102 | 103 | 157 | 139 | 179 | 32 | 144 |
| | 92 | 131 | 75 | 155 | 14 | 9 | 149 | 63 | 11 | 134 | 53 | 99 | 17 | 57 | 90 | 30 | 98 | 64 | 40 | 87 | 158 | 77 | 93 |
| | 124 | 46 | 171 | 141 | 133 | 85 | 177 | 132 | 26 | 160 | 42 | 34 | 82 | 96 | 48 | 10 | 142 | 125 | 178 | 153 | 72 | 45 | 89 |
| | 52 | 28 | 126 | 143 | 167 | 76 | 86 | 130 | 110 | 174 | 16 | 165 | 56 | 84 | 95 | 0 | 106 | 12 | 71 | | | | |
| 3/15 | 136 | 28 | 85 | 38 | 40 | 89 | 133 | 117 | 3 | 58 | 154 | 77 | 14 | 179 | 96 | 101 | 26 | 169 | 37 | 83 | 162 | 165 | 24 |
| | 66 | 109 | 126 | 10 | 155 | 70 | 157 | 105 | 175 | 67 | 158 | 32 | 42 | 147 | 140 | 30 | 7 | 92 | 59 | 119 | 56 | 0 | 5 |
| | 90 | 174 | 13 | 47 | 76 | 88 | 86 | 108 | 27 | 18 | 12 | 8 | 61 | 145 | 75 | 125 | 112 | 69 | 120 | 137 | 116 | 20 | 178 |
| | 98 | 176 | 29 | 68 | 168 | 124 | 21 | 35 | 150 | 131 | 159 | 163 | 84 | 23 | 123 | 65 | 103 | 93 | 99 | 102 | 31 | 64 | 74 |
| | 46 | 94 | 80 | 129 | 142 | 128 | 148 | 111 | 134 | 173 | 60 | 118 | 2 | 170 | 135 | 1 | 115 | 143 | 95 | 177 | 73 | 43 | 11 |
| | 114 | 91 | 78 | 107 | 172 | 25 | 36 | 164 | 149 | 153 | 110 | 44 | 146 | 82 | 127 | 45 | 33 | 50 | 41 | 52 | 156 | 34 | 4 |
| | 79 | 141 | 138 | 122 | 53 | 160 | 81 | 16 | 100 | 130 | 71 | 121 | 132 | 9 | 22 | 113 | 6 | 152 | 15 | 171 | 17 | 57 | 49 |
| | 151 | 161 | 63 | 55 | 139 | 166 | 97 | 19 | 51 | 72 | 167 | 106 | 48 | 144 | 87 | 104 | 62 | 54 | 39 | | | | |
| 4/15 | 13 | 121 | 137 | 29 | 27 | 1 | 70 | 116 | 35 | 132 | 109 | 51 | 55 | 58 | 11 | 67 | 136 | 25 | 145 | 7 | 75 | 107 | 45 |
| | 21 | 127 | 52 | 90 | 22 | 100 | 123 | 69 | 112 | 155 | 92 | 151 | 59 | 5 | 179 | 44 | 87 | 56 | 139 | 65 | 170 | 46 | 0 |
| | 124 | 78 | 166 | 8 | 61 | 97 | 120 | 103 | 4 | 19 | 64 | 79 | 28 | 134 | 93 | 86 | 60 | 135 | 126 | 53 | 63 | 14 | 122 |
| | 17 | 150 | 76 | 42 | 39 | 23 | 153 | 95 | 66 | 50 | 141 | 176 | 34 | 161 | 26 | 106 | 10 | 43 | 85 | 131 | 2 | 147 | 148 |
| | 144 | 54 | 115 | 146 | 101 | 172 | 114 | 119 | 3 | 96 | 133 | 99 | 167 | 164 | 9 | 142 | 68 | 149 | 94 | 83 | 16 | 175 | 73 |
| | 38 | 143 | 159 | 130 | 84 | 169 | 18 | 138 | 102 | 72 | 47 | 32 | 160 | 82 | 81 | 168 | 30 | 12 | 173 | 156 | 158 | 125 | 98 |
| | 62 | 178 | 48 | 163 | 117 | 110 | 91 | 37 | 80 | 105 | 31 | 174 | 111 | 49 | 113 | 108 | 74 | 157 | 128 | 24 | 118 | 40 | 88 |
| | 177 | 154 | 6 | 162 | 129 | 77 | 36 | 165 | 20 | 89 | 140 | 15 | 33 | 104 | 152 | 71 | 171 | 57 | 41 | | | | |
| 5/15 | 39 | 45 | 128 | 84 | 143 | 148 | 2 | 75 | 43 | 50 | 130 | 87 | 137 | 151 | 7 | 71 | 55 | 51 | 133 | 90 | 140 | 149 | 6 |
| | 177 | 37 | 124 | 99 | 83 | 23 | 159 | 0 | 176 | 41 | 121 | 96 | 89 | 30 | 161 | 18 | 172 | 60 | 49 | 134 | 104 | 139 | 166 |
| | 14 | 179 | 62 | 48 | 129 | 105 | 146 | 160 | 16 | 174 | 33 | 54 | 132 | 112 | 145 | 150 | 9 | 77 | 34 | 117 | 92 | 82 | 136 |
| | 165 | 4 | 67 | 36 | 44 | 101 | 81 | 141 | 156 | 3 | 175 | 58 | 47 | 91 | 102 | 32 | 158 | 13 | 178 | 63 | 118 | 100 | 85 |
| | 26 | 167 | 1 | 173 | 38 | 116 | 131 | 107 | 138 | 162 | 8 | 72 | 42 | 115 | 98 | 108 | 24 | 152 | 17 | 171 | 64 | 123 | 94 |
| | 110 | 28 | 147 | 19 | 169 | 61 | 46 | 97 | 106 | 144 | 164 | 5 | 70 | 59 | 53 | 127 | 88 | 31 | 153 | 10 | 73 | 66 | 119 |
| | 126 | 111 | 29 | 155 | 15 | 170 | 57 | 120 | 125 | 80 | 142 | 168 | 11 | 68 | 56 | 52 | 95 | 103 | 27 | 154 | 21 | 78 | 40 |
| | 122 | 93 | 86 | 25 | 163 | 20 | 79 | 35 | 114 | 135 | 109 | 22 | 157 | 12 | 69 | 65 | 74 | 76 | 113 | | | | |
| 6/15 | 99 | 100 | 15 | 107 | 54 | 76 | 153 | 174 | 61 | 0 | 36 | 71 | 62 | 137 | 108 | 114 | 65 | 98 | 151 | 19 | 112 | 109 | 152 |
| | 117 | 35 | 93 | 43 | 90 | 154 | 73 | 150 | 165 | 23 | 16 | 91 | 5 | 169 | 175 | 120 | 149 | 26 | 59 | 49 | 56 | 156 | 136 |
| | 110 | 80 | 58 | 55 | 40 | 103 | 159 | 83 | 127 | 111 | 155 | 167 | 11 | 52 | 116 | 142 | 133 | 1 | 2 | 96 | 77 | 86 | 122 |
| | 6 | 131 | 29 | 51 | 21 | 17 | 45 | 126 | 12 | 3 | 168 | 41 | 30 | 37 | 64 | 164 | 78 | 8 | 118 | 113 | 39 | 48 | 140 |
| | 14 | 60 | 82 | 134 | 25 | 33 | 50 | 84 | 28 | 105 | 123 | 145 | 7 | 27 | 34 | 92 | 115 | 147 | 74 | 10 | 68 | 102 | 67 |
| | 63 | 101 | 18 | 66 | 129 | 24 | 4 | 119 | 87 | 42 | 170 | 143 | 121 | 38 | 57 | 95 | 148 | 89 | 81 | 158 | 171 | 32 | 22 |
| | 69 | 53 | 130 | 104 | 161 | 75 | 141 | 9 | 47 | 79 | 162 | 146 | 124 | 157 | 70 | 106 | 31 | 132 | 166 | 128 | 138 | 125 | 44 |
| | 13 | 85 | 88 | 135 | 144 | 173 | 163 | 20 | 46 | 97 | 94 | 139 | 172 | 72 | 160 | 176 | 177 | 178 | 179 | | | | |
| 7/15 | 24 | 157 | 0 | 43 | 126 | 172 | 135 | 65 | 32 | 18 | 114 | 42 | 162 | 67 | 104 | 61 | 23 | 11 | 4 | 96 | 163 | 75 | 109 |
| | 58 | 79 | 154 | 3 | 95 | 168 | 73 | 103 | 60 | 84 | 148 | 113 | 40 | 164 | 173 | 143 | 49 | 29 | 156 | 7 | 89 | 132 | 179 |
| | 138 | 53 | 85 | 12 | 117 | 36 | 122 | 66 | 107 | 64 | 28 | 147 | 2 | 90 | 131 | 70 | 144 | 55 | 26 | 15 | 112 | 35 | 128 |
| | 176 | 106 | 59 | 80 | 19 | 6 | 92 | 129 | 174 | 99 | 62 | 82 | 13 | 121 | 41 | 127 | 71 | 139 | 63 | 25 | 151 | 9 | 39 |

| | | | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 159 | 69 | 142 | 52 | 77 | 21 | 119 | 38 | 167 | 178 | 101 | 56 | 87 | 155 | 5 | 91 | 166 | 169 | 146 | 50 | 81 | 20 | 111 |
| | 88 | 165 | 177 | 108 | 47 | 27 | 149 | 115 | 33 | 161 | 72 | 102 | 57 | 86 | 16 | 110 | 97 | 123 | 68 | 100 | 48 | 31 | 14 |
| | 8 | 93 | 130 | 170 | 133 | 44 | 78 | 150 | 118 | 94 | 158 | 76 | 134 | 46 | 83 | 152 | 1 | 37 | 160 | 171 | 136 | 54 | 22 |
| | 17 | 116 | 34 | 125 | 175 | 105 | 45 | 30 | 153 | 10 | 98 | 124 | 74 | 137 | 51 | 120 | 141 | 140 | 145 | | | | |
| **8/15** | 85 | 3 | 148 | 161 | 96 | 99 | 154 | 13 | 78 | 160 | 61 | 36 | 21 | 141 | 121 | 115 | 82 | 1 | 59 | 72 | 43 | 135 | 168 |
| | 139 | 46 | 10 | 56 | 67 | 108 | 134 | 111 | 105 | 66 | 89 | 137 | 130 | 104 | 143 | 113 | 11 | 84 | 157 | 32 | 73 | 90 | 38 |
| | 117 | 146 | 53 | 2 | 60 | 93 | 91 | 71 | 114 | 19 | 47 | 4 | 26 | 75 | 109 | 41 | 50 | 153 | 54 | 163 | 31 | 24 | 106 |
| | 42 | 170 | 62 | 80 | 164 | 65 | 128 | 12 | 142 | 167 | 155 | 88 | 8 | 22 | 131 | 158 | 33 | 178 | 145 | 70 | 9 | 51 | 69 |
| | 102 | 140 | 173 | 147 | 83 | 165 | 30 | 126 | 100 | 138 | 171 | 103 | 45 | 159 | 27 | 74 | 97 | 122 | 120 | 16 | 52 | 162 | 132 |
| | 124 | 94 | 133 | 172 | 149 | 86 | 77 | 25 | 68 | 177 | 64 | 174 | 15 | 0 | 125 | 63 | 35 | 34 | 40 | 179 | 20 | 44 | 7 |
| | 55 | 28 | 101 | 150 | 110 | 18 | 119 | 5 | 29 | 76 | 107 | 136 | 112 | 144 | 48 | 81 | 57 | 49 | 92 | 95 | 118 | 17 | 156 |
| | 166 | 23 | 129 | 79 | 37 | 175 | 152 | 87 | 6 | 58 | 127 | 98 | 123 | 39 | 14 | 116 | 169 | 176 | 151 | | | | |
| **9/15** | 58 | 70 | 23 | 32 | 26 | 63 | 55 | 48 | 35 | 41 | 53 | 20 | 38 | 51 | 61 | 65 | 44 | 29 | 7 | 2 | 113 | 68 | 96 |
| | 104 | 106 | 89 | 27 | 0 | 119 | 21 | 4 | 49 | 46 | 100 | 13 | 36 | 57 | 98 | 102 | 9 | 42 | 39 | 33 | 62 | 22 | 95 |
| | 101 | 15 | 91 | 25 | 93 | 132 | 69 | 87 | 47 | 59 | 67 | 124 | 17 | 11 | 31 | 43 | 40 | 37 | 85 | 50 | 97 | 140 | 45 |
| | 92 | 56 | 30 | 34 | 60 | 107 | 24 | 52 | 94 | 64 | 5 | 71 | 90 | 66 | 103 | 88 | 86 | 84 | 19 | 169 | 159 | 147 | 126 |
| | 28 | 130 | 14 | 162 | 144 | 166 | 108 | 153 | 115 | 135 | 120 | 122 | 112 | 139 | 151 | 156 | 16 | 172 | 164 | 123 | 99 | 54 | 136 |
| | 81 | 105 | 128 | 116 | 150 | 155 | 76 | 18 | 142 | 170 | 175 | 83 | 146 | 78 | 109 | 73 | 131 | 127 | 82 | 167 | 77 | 110 | 79 |
| | 137 | 152 | 3 | 173 | 148 | 72 | 158 | 117 | 1 | 6 | 12 | 8 | 161 | 74 | 143 | 133 | 168 | 171 | 134 | 163 | 138 | 121 | 141 |
| | 160 | 111 | 10 | 149 | 80 | 75 | 165 | 157 | 174 | 129 | 145 | 114 | 125 | 154 | 118 | 176 | 177 | 178 | 179 | | | | |
| **10/15** | 45 | 31 | 67 | 35 | 159 | 157 | 177 | 2 | 44 | 23 | 73 | 148 | 163 | 118 | 176 | 4 | 14 | 97 | 142 | 37 | 143 | 149 | 179 |
| | 3 | 12 | 32 | 140 | 42 | 167 | 166 | 41 | 126 | 13 | 30 | 144 | 57 | 113 | 147 | 173 | 6 | 52 | 24 | 39 | 64 | 80 | 112 |
| | 104 | 174 | 11 | 151 | 71 | 109 | 162 | 79 | 171 | 127 | 46 | 92 | 38 | 132 | 81 | 120 | 100 | 1 | 53 | 88 | 76 | 60 | 103 |
| | 139 | 99 | 125 | 48 | 93 | 135 | 161 | 77 | 110 | 107 | 121 | 18 | 95 | 69 | 63 | 83 | 111 | 170 | 7 | 16 | 98 | 141 | 61 |
| | 86 | 116 | 172 | 130 | 49 | 25 | 40 | 65 | 87 | 108 | 101 | 5 | 21 | 89 | 75 | 43 | 82 | 146 | 105 | 128 | 17 | 29 | 106 |
| | 34 | 160 | 155 | 175 | 124 | 15 | 28 | 134 | 62 | 119 | 145 | 72 | 10 | 58 | 91 | 74 | 36 | 68 | 150 | 8 | 9 | 54 | 26 |
| | 137 | 56 | 165 | 115 | 114 | 0 | 47 | 27 | 22 | 20 | 168 | 154 | 102 | 123 | 50 | 94 | 66 | 33 | 85 | 59 | 164 | 131 | 51 |
| | 90 | 70 | 138 | 84 | 117 | 178 | 122 | 19 | 96 | 156 | 55 | 78 | 158 | 169 | 129 | 133 | 152 | 136 | 153 | | | | |
| **11/15** | 27 | 68 | 35 | 117 | 138 | 83 | 127 | 10 | 60 | 73 | 47 | 115 | 155 | 81 | 170 | 9 | 65 | 66 | 52 | 112 | 150 | 77 | 171 |
| | 161 | 22 | 20 | 39 | 106 | 147 | 90 | 126 | 165 | 23 | 16 | 45 | 113 | 154 | 86 | 173 | 158 | 24 | 71 | 40 | 107 | 136 | 94 |
| | 128 | 163 | 31 | 72 | 33 | 101 | 134 | 80 | 175 | 7 | 61 | 19 | 49 | 111 | 135 | 92 | 130 | 6 | 62 | 74 | 43 | 116 | 133 |
| | 89 | 129 | 8 | 28 | 15 | 34 | 105 | 146 | 84 | 174 | 4 | 32 | 75 | 44 | 118 | 132 | 96 | 169 | 159 | 58 | 18 | 42 | 100 |
| | 141 | 87 | 131 | 157 | 63 | 11 | 48 | 108 | 151 | 79 | 177 | 168 | 26 | 17 | 36 | 102 | 137 | 95 | 122 | 1 | 25 | 21 | 50 |
| | 120 | 153 | 97 | 121 | 0 | 55 | 14 | 46 | 114 | 152 | 91 | 178 | 3 | 30 | 13 | 37 | 103 | 145 | 82 | 125 | 166 | 57 | 76 |
| | 51 | 99 | 144 | 85 | 123 | 162 | 56 | 12 | 53 | 119 | 139 | 78 | 179 | 5 | 64 | 70 | 54 | 110 | 148 | 93 | 172 | 164 | 29 |
| | 69 | 38 | 109 | 143 | 88 | 124 | 160 | 59 | 67 | 41 | 104 | 149 | 98 | 176 | 2 | 167 | 156 | 140 | 142 | | | | |
| 12/15 | 51 | 122 | 91 | 111 | 95 | 100 | 119 | 130 | 78 | 57 | 65 | 26 | 61 | 126 | 105 | 143 | 70 | 132 | 39 | 102 | 115 | 116 | 6 |
| | 14 | 3 | 21 | 71 | 134 | 2 | 0 | 140 | 106 | 7 | 118 | 23 | 35 | 20 | 17 | 50 | 48 | 112 | 13 | 66 | 5 | 75 | 42 |
| | 129 | 107 | 30 | 45 | 137 | 114 | 37 | 87 | 53 | 85 | 101 | 141 | 120 | 99 | 88 | 117 | 64 | 28 | 135 | 138 | 108 | 113 | 58 |
| | 97 | 38 | 124 | 86 | 33 | 74 | 32 | 29 | 128 | 67 | 104 | 80 | 127 | 56 | 34 | 89 | 94 | 49 | 55 | 93 | 136 | 68 | 62 |
| | 54 | 40 | 81 | 103 | 121 | 76 | 44 | 84 | 96 | 123 | 154 | 98 | 82 | 142 | 46 | 169 | 131 | 72 | 47 | 69 | 125 | 31 | 83 |
| | 36 | 59 | 90 | 79 | 52 | 133 | 60 | 92 | 139 | 110 | 27 | 73 | 43 | 77 | 109 | 63 | 41 | 168 | 147 | 161 | 165 | 175 | 162 |
| | 164 | 158 | 157 | 160 | 150 | 171 | 167 | 145 | 151 | 153 | 9 | 155 | 170 | 146 | 166 | 149 | 15 | 159 | 11 | 176 | 152 | 156 | 144 |
| | 148 | 172 | 178 | 24 | 22 | 179 | 4 | 163 | 174 | 173 | 19 | 10 | 177 | 12 | 16 | 1 | 8 | 18 | 25 | | | | |
| **13/15** | 59 | 85 | 108 | 128 | 49 | 91 | 163 | 3 | 58 | 16 | 106 | 126 | 74 | 141 | 167 | 35 | 57 | 82 | 30 | 123 | 68 | 95 | 160 |
| | 42 | 62 | 21 | 102 | 131 | 52 | 142 | 157 | 10 | 55 | 79 | 24 | 130 | 73 | 92 | 179 | 2 | 61 | 11 | 104 | 122 | 45 | 140 |
| | 159 | 43 | 148 | 19 | 23 | 111 | 76 | 135 | 169 | 39 | 63 | 77 | 25 | 117 | 75 | 94 | 155 | 5 | 145 | 14 | 26 | 127 | 46 |
| | 138 | 158 | 38 | 64 | 86 | 105 | 118 | 50 | 137 | 175 | 7 | 144 | 84 | 22 | 113 | 54 | 98 | 172 | 9 | 146 | 17 | 27 | 114 |
| | 51 | 139 | 156 | 37 | 147 | 78 | 103 | 115 | 66 | 97 | 168 | 34 | 60 | 83 | 107 | 121 | 48 | 93 | 174 | 33 | 65 | 87 | 99 |
| | 124 | 71 | 136 | 154 | 0 | 150 | 20 | 101 | 112 | 70 | 96 | 170 | 1 | 149 | 80 | 28 | 125 | 53 | 90 | 173 | 6 | 153 | 13 |
| | 29 | 116 | 72 | 88 | 165 | 8 | 143 | 12 | 31 | 119 | 47 | 89 | 164 | 40 | 151 | 81 | 109 | 110 | 44 | 134 | 162 | 36 | 152 |
| | 15 | 100 | 129 | 67 | 133 | 166 | 41 | 56 | 18 | 32 | 120 | 69 | 132 | 161 | 4 | 177 | 176 | 178 | 171 | | | | |

**Table B.1.5** 1024QAM ($N_{inner}$ = 64800)

| Code Rate | Order of Group-Wise Interleaving π(j) (0 ≤ j < 180) | | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 |
| | 23 | 24 | 25 | 26 | 27 | 28 | 29 | 30 | 31 | 32 | 33 | 34 | 35 | 36 | 37 | 38 | 39 | 40 | 41 | 42 | 43 | 44 | 45 |
| | 46 | 47 | 48 | 49 | 50 | 51 | 52 | 53 | 54 | 55 | 56 | 57 | 58 | 59 | 60 | 61 | 62 | 63 | 64 | 65 | 66 | 67 | 68 |
| | 69 | 70 | 71 | 72 | 73 | 74 | 75 | 76 | 77 | 78 | 79 | 80 | 81 | 82 | 83 | 84 | 85 | 86 | 87 | 88 | 89 | 90 | 91 |
| | 92 | 93 | 94 | 95 | 96 | 97 | 98 | 99 | 100 | 101 | 102 | 103 | 104 | 105 | 106 | 107 | 108 | 109 | 110 | 111 | 112 | 113 | 114 |
| | 115 | 116 | 117 | 118 | 119 | 120 | 121 | 122 | 123 | 124 | 125 | 126 | 127 | 128 | 129 | 130 | 131 | 132 | 133 | 134 | 135 | 136 | 137 |
| | 138 | 139 | 140 | 141 | 142 | 143 | 144 | 145 | 146 | 147 | 148 | 149 | 150 | 151 | 152 | 153 | 154 | 155 | 156 | 157 | 158 | 159 | 160 |
| | 161 | 162 | 163 | 164 | 165 | 166 | 167 | 168 | 169 | 170 | 171 | 172 | 173 | 174 | 175 | 176 | 177 | 178 | 179 | | | | |
| 2/15 | 157 | 25 | 107 | 160 | 37 | 138 | 111 | 35 | 29 | 44 | 15 | 162 | 66 | 20 | 49 | 126 | 89 | 147 | 159 | 174 | 142 | 26 | 146 |
| | 10 | 164 | 152 | 57 | 110 | 83 | 167 | 169 | 16 | 6 | 172 | 62 | 173 | 7 | 145 | 4 | 67 | 115 | 50 | 39 | 72 | 79 | 74 |
| | 40 | 132 | 42 | 30 | 163 | 161 | 55 | 143 | 63 | 117 | 86 | 121 | 2 | 28 | 69 | 150 | 24 | 177 | 43 | 158 | 27 | 21 | 128 |
| | 46 | 118 | 114 | 127 | 135 | 92 | 76 | 19 | 94 | 179 | 3 | 52 | 101 | 137 | 84 | 73 | 108 | 91 | 120 | 47 | 1 | 102 | 58 |
| | 68 | 82 | 59 | 119 | 64 | 31 | 61 | 105 | 103 | 151 | 124 | 70 | 8 | 155 | 90 | 166 | 41 | 45 | 178 | 113 | 140 | 75 | 148 |
| | 109 | 100 | 125 | 11 | 116 | 34 | 36 | 176 | 170 | 156 | 136 | 171 | 122 | 78 | 87 | 106 | 123 | 149 | 17 | 99 | 175 | 18 | 9 |
| | 165 | 153 | 12 | 81 | 77 | 60 | 93 | 104 | 13 | 5 | 88 | 96 | 141 | 133 | 154 | 144 | 48 | 97 | 23 | 14 | 98 | 53 | 134 |
| | 112 | 65 | 0 | 130 | 32 | 168 | 33 | 131 | 22 | 38 | 56 | 80 | 95 | 71 | 85 | 139 | 129 | 51 | 54 | | | | |
| 3/15 | 113 | 153 | 13 | 8 | 103 | 115 | 137 | 69 | 151 | 111 | 18 | 38 | 42 | 150 | 179 | 130 | 148 | 6 | 4 | 31 | 44 | 68 | 145 |
| | 126 | 106 | 24 | 100 | 93 | 21 | 35 | 143 | 57 | 166 | 65 | 53 | 41 | 122 | 7 | 29 | 25 | 136 | 162 | 158 | 26 | 124 | 32 |
| | 17 | 168 | 56 | 12 | 39 | 176 | 131 | 132 | 51 | 89 | 101 | 160 | 49 | 87 | 14 | 55 | 127 | 37 | 169 | 110 | 83 | 134 | 107 |
| | 46 | 33 | 114 | 108 | 82 | 125 | 109 | 95 | 174 | 62 | 164 | 144 | 16 | 121 | 58 | 80 | 2 | 163 | 159 | 157 | 90 | 104 | 23 |
| | 172 | 112 | 19 | 133 | 102 | 75 | 45 | 86 | 63 | 22 | 54 | 105 | 155 | 77 | 178 | 70 | 98 | 40 | 118 | 84 | 78 | 0 | 99 |
| | 123 | 5 | 34 | 71 | 96 | 175 | 10 | 30 | 72 | 28 | 74 | 154 | 61 | 91 | 85 | 135 | 152 | 15 | 88 | 165 | 60 | 52 | 149 |
| | 147 | 59 | 116 | 120 | 3 | 64 | 140 | 67 | 94 | 27 | 9 | 81 | 43 | 11 | 167 | 139 | 92 | 129 | 20 | 117 | 128 | 50 | 119 |
| | 47 | 1 | 156 | 142 | 170 | 171 | 48 | 177 | 66 | 161 | 79 | 73 | 76 | 173 | 97 | 36 | 141 | 146 | 138 | | | | |
| 4/15 | 114 | 133 | 4 | 73 | 8 | 139 | 7 | 5 | 177 | 88 | 66 | 11 | 24 | 74 | 49 | 45 | 167 | 81 | 117 | 137 | 46 | 22 | 165 |
| | 51 | 68 | 110 | 6 | 1 | 16 | 132 | 130 | 143 | 169 | 2 | 20 | 140 | 94 | 21 | 91 | 126 | 172 | 27 | 162 | 34 | 113 | 142 |
| | 166 | 115 | 106 | 160 | 84 | 136 | 175 | 0 | 26 | 151 | 69 | 174 | 59 | 159 | 161 | 170 | 52 | 164 | 80 | 108 | 3 | 23 | 101 |
| | 33 | 125 | 111 | 63 | 124 | 98 | 40 | 145 | 9 | 39 | 155 | 149 | 147 | 67 | 76 | 48 | 120 | 119 | 53 | 54 | 138 | 179 | 156 |
| | 127 | 13 | 152 | 129 | 123 | 141 | 109 | 89 | 121 | 50 | 10 | 37 | 104 | 144 | 86 | 178 | 96 | 148 | 128 | 56 | 64 | 153 | 95 |
| | 12 | 105 | 41 | 154 | 99 | 25 | 171 | 92 | 17 | 134 | 19 | 61 | 32 | 85 | 102 | 14 | 71 | 146 | 163 | 173 | 118 | 57 | 18 |
| | 36 | 42 | 78 | 31 | 97 | 55 | 58 | 116 | 90 | 168 | 43 | 72 | 15 | 112 | 93 | 60 | 38 | 103 | 87 | 158 | 35 | 29 | 176 |
| | 150 | 77 | 79 | 122 | 47 | 28 | 135 | 100 | 83 | 65 | 131 | 75 | 157 | 62 | 70 | 44 | 30 | 107 | 82 | | | | |
| 5/15 | 128 | 4 | 162 | 8 | 77 | 29 | 91 | 44 | 176 | 107 | 149 | 1 | 150 | 9 | 119 | 99 | 71 | 124 | 104 | 41 | 62 | 5 | 118 |
| | 50 | 174 | 54 | 111 | 40 | 156 | 92 | 46 | 11 | 17 | 52 | 47 | 97 | 179 | 24 | 153 | 145 | 129 | 2 | 12 | 88 | 101 | 139 |
| | 114 | 69 | 96 | 32 | 134 | 55 | 167 | 132 | 123 | 136 | 112 | 102 | 159 | 31 | 87 | 141 | 15 | 61 | 84 | 98 | 37 | 63 | 20 |
| | 85 | 53 | 7 | 39 | 117 | 170 | 138 | 116 | 126 | 161 | 120 | 57 | 13 | 76 | 6 | 121 | 155 | 175 | 38 | 158 | 35 | 86 | 78 |
| | 10 | 103 | 166 | 95 | 125 | 172 | 67 | 30 | 177 | 73 | 151 | 169 | 163 | 23 | 108 | 43 | 81 | 157 | 58 | 105 | 65 | 26 | 122 |
| | 135 | 146 | 72 | 142 | 34 | 133 | 0 | 148 | 89 | 168 | 60 | 109 | 83 | 18 | 27 | 131 | 70 | 56 | 48 | 64 | 93 | 68 | 127 |
| | 21 | 75 | 110 | 80 | 14 | 49 | 82 | 143 | 115 | 178 | 154 | 100 | 59 | 74 | 152 | 51 | 137 | 140 | 36 | 42 | 19 | 25 | 94 |
| | 45 | 164 | 16 | 113 | 79 | 22 | 28 | 66 | 106 | 130 | 171 | 147 | 90 | 144 | 165 | 3 | 173 | 160 | 33 | | | | |
| 6/15 | 66 | 21 | 51 | 55 | 54 | 24 | 33 | 12 | 70 | 63 | 47 | 65 | 145 | 8 | 0 | 57 | 23 | 71 | 59 | 14 | 40 | 42 | 62 |
| | 56 | 2 | 43 | 64 | 58 | 67 | 53 | 68 | 61 | 39 | 52 | 69 | 1 | 22 | 31 | 161 | 38 | 30 | 19 | 17 | 18 | 4 | 41 |
| | 25 | 44 | 136 | 29 | 36 | 26 | 126 | 177 | 15 | 37 | 148 | 9 | 13 | 45 | 46 | 152 | 50 | 49 | 27 | 77 | 60 | 35 | 48 |
| | 178 | 28 | 34 | 106 | 127 | 76 | 131 | 105 | 138 | 75 | 130 | 101 | 167 | 117 | 173 | 113 | 108 | 92 | 135 | 124 | 121 | 97 | 149 |
| | 143 | 81 | 32 | 96 | 3 | 78 | 107 | 86 | 98 | 16 | 162 | 150 | 111 | 158 | 172 | 139 | 74 | 142 | 166 | 7 | 5 | 119 | 20 |
| | 144 | 151 | 90 | 11 | 156 | 100 | 175 | 83 | 155 | 159 | 128 | 88 | 87 | 93 | 103 | 94 | 140 | 165 | 6 | 137 | 157 | 10 | 85 |
| | 141 | 129 | 146 | 122 | 73 | 112 | 132 | 125 | 174 | 169 | 168 | 79 | 84 | 118 | 179 | 147 | 91 | 160 | 163 | 115 | 89 | 80 | 102 |
| | 104 | 134 | 82 | 95 | 133 | 164 | 154 | 120 | 110 | 170 | 114 | 153 | 72 | 109 | 171 | 176 | 99 | 116 | 123 | | | | |
| 7/15 | 117 | 61 | 46 | 179 | 24 | 161 | 142 | 133 | 11 | 6 | 121 | 44 | 103 | 76 | 22 | 63 | 136 | 151 | 33 | 8 | 123 | 60 | 105 |
| | 175 | 18 | 160 | 138 | 147 | 10 | 0 | 125 | 57 | 49 | 75 | 21 | 154 | 140 | 150 | 9 | 169 | 124 | 55 | 48 | 173 | 23 | 157 |
| | 97 | 129 | 30 | 7 | 122 | 54 | 99 | 74 | 19 | 153 | 94 | 128 | 15 | 170 | 87 | 59 | 51 | 80 | 111 | 64 | 137 | 146 | 13 |
| | 2 | 83 | 62 | 45 | 176 | 108 | 71 | 91 | 131 | 34 | 168 | 82 | 56 | 102 | 72 | 26 | 155 | 92 | 132 | 31 | 166 | 119 | 36 |

| | | | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 101 | 178 | 113 | 67 | 98 | 152 | 14 | 5 | 118 | 41 | 104 | 177 | 114 | 70 | 96 | 134 | 32 | 162 | 84 | 40 | 100 | 174 | 110 |
| | 158 | 93 | 149 | 27 | 4 | 86 | 38 | 53 | 77 | 115 | 159 | 143 | 130 | 35 | 163 | 89 | 58 | 106 | 73 | 20 | 66 | 90 | 127 |
| | 16 | 3 | 85 | 37 | 107 | 172 | 116 | 156 | 95 | 144 | 17 | 165 | 81 | 43 | 50 | 78 | 109 | 68 | 135 | 126 | 29 | 167 | 120 |
| | 39 | 47 | 171 | 112 | 69 | 141 | 145 | 28 | 1 | 88 | 42 | 52 | 79 | 25 | 65 | 139 | 148 | 12 | 164 | | | | |
| **8/15** | 77 | 48 | 82 | 51 | 57 | 69 | 65 | 6 | 71 | 90 | 84 | 81 | 50 | 88 | 61 | 55 | 53 | 73 | 39 | 13 | 79 | 75 | 41 |
| | 18 | 38 | 89 | 49 | 93 | 36 | 64 | 47 | 40 | 42 | 76 | 70 | 56 | 3 | 72 | 2 | 54 | 52 | 145 | 19 | 78 | 80 | 63 |
| | 87 | 67 | 86 | 10 | 1 | 58 | 17 | 14 | 175 | 91 | 68 | 85 | 94 | 15 | 43 | 74 | 60 | 66 | 37 | 92 | 4 | 9 | 16 |
| | 83 | 46 | 44 | 102 | 30 | 112 | 122 | 110 | 29 | 20 | 105 | 138 | 101 | 174 | 33 | 137 | 136 | 131 | 166 | 59 | 34 | 62 | 125 |
| | 28 | 26 | 45 | 24 | 23 | 21 | 157 | 98 | 35 | 95 | 22 | 32 | 103 | 27 | 113 | 31 | 119 | 173 | 168 | 118 | 120 | 114 | 149 |
| | 159 | 155 | 179 | 160 | 161 | 130 | 123 | 172 | 139 | 124 | 153 | 0 | 109 | 167 | 128 | 107 | 117 | 147 | 177 | 96 | 164 | 152 | 11 |
| | 148 | 158 | 129 | 163 | 176 | 151 | 171 | 8 | 106 | 144 | 150 | 169 | 108 | 162 | 143 | 111 | 141 | 133 | 178 | 134 | 146 | 99 | 132 |
| | 142 | 104 | 115 | 135 | 121 | 100 | 12 | 170 | 156 | 126 | 5 | 127 | 154 | 97 | 140 | 116 | 165 | 7 | 25 | | | | |
| **9/15** | 42 | 36 | 135 | 126 | 3 | 17 | 82 | 87 | 172 | 32 | 65 | 70 | 143 | 131 | 10 | 1 | 85 | 147 | 31 | 176 | 66 | 47 | 97 |
| | 128 | 8 | 9 | 146 | 73 | 162 | 164 | 57 | 64 | 139 | 91 | 5 | 110 | 150 | 83 | 18 | 27 | 48 | 45 | 133 | 132 | 111 | 124 |
| | 89 | 78 | 177 | 19 | 46 | 50 | 102 | 103 | 122 | 4 | 74 | 161 | 175 | 34 | 60 | 58 | 136 | 100 | 115 | 118 | 81 | 75 | 28 |
| | 21 | 40 | 61 | 140 | 138 | 113 | 112 | 157 | 151 | 23 | 30 | 69 | 41 | 94 | 96 | 7 | 109 | 152 | 149 | 33 | 179 | 71 | 43 |
| | 92 | 105 | 12 | 13 | 154 | 159 | 178 | 24 | 44 | 49 | 107 | 98 | 16 | 2 | 76 | 155 | 35 | 168 | 62 | 56 | 129 | 141 | 116 |
| | 123 | 160 | 77 | 25 | 170 | 54 | 39 | 90 | 95 | 121 | 11 | 72 | 153 | 169 | 167 | 51 | 67 | 104 | 134 | 0 | 117 | 79 | 80 |
| | 26 | 29 | 37 | 55 | 99 | 142 | 108 | 114 | 86 | 88 | 166 | 163 | 59 | 63 | 101 | 93 | 119 | 15 | 144 | 145 | 165 | 22 | 52 |
| | 53 | 130 | 137 | 125 | 6 | 158 | 84 | 20 | 174 | 38 | 68 | 127 | 106 | 14 | 120 | 148 | 156 | 171 | 173 | | | | |
| **10/15** | 100 | 22 | 60 | 121 | 40 | 44 | 164 | 170 | 176 | 101 | 88 | 26 | 35 | 4 | 21 | 173 | 140 | 145 | 175 | 174 | 81 | 28 | 72 |
| | 112 | 132 | 106 | 42 | 56 | 151 | 147 | 82 | 49 | 91 | 64 | 179 | 89 | 160 | 52 | 139 | 17 | 97 | 63 | 116 | 131 | 154 | 71 |
| | 109 | 96 | 135 | 146 | 55 | 38 | 166 | 117 | 65 | 127 | 120 | 129 | 15 | 136 | 74 | 23 | 98 | 43 | 123 | 130 | 69 | 99 | 143 |
| | 161 | 46 | 51 | 94 | 61 | 83 | 67 | 156 | 33 | 144 | 148 | 163 | 47 | 92 | 2 | 122 | 24 | 86 | 75 | 108 | 152 | 14 | 77 |
| | 7 | 10 | 29 | 19 | 104 | 128 | 142 | 1 | 79 | 107 | 162 | 0 | 118 | 66 | 54 | 153 | 141 | 9 | 85 | 37 | 32 | 114 | 53 |
| | 134 | 41 | 158 | 178 | 138 | 76 | 50 | 78 | 84 | 172 | 48 | 133 | 168 | 125 | 13 | 169 | 25 | 16 | 8 | 124 | 159 | 167 | 58 |
| | 5 | 11 | 68 | 95 | 27 | 110 | 93 | 62 | 102 | 137 | 126 | 150 | 87 | 105 | 113 | 30 | 119 | 6 | 103 | 57 | 31 | 149 | 80 |
| | 70 | 45 | 165 | 111 | 73 | 36 | 157 | 171 | 3 | 20 | 18 | 90 | 12 | 59 | 39 | 115 | 34 | 177 | 155 | | | | |
| **11/15** | 33 | 73 | 90 | 107 | 99 | 94 | 53 | 151 | 124 | 8 | 12 | 117 | 21 | 58 | 158 | 77 | 72 | 59 | 123 | 2 | 125 | 157 | 50 |
| | 62 | 109 | 75 | 42 | 146 | 118 | 153 | 85 | 10 | 131 | 70 | 32 | 41 | 24 | 143 | 113 | 1 | 93 | 162 | 20 | 35 | 74 | 45 |
| | 149 | 161 | 173 | 4 | 28 | 23 | 127 | 148 | 34 | 61 | 96 | 144 | 171 | 140 | 119 | 16 | 126 | 39 | 40 | 57 | 165 | 106 | 172 |
| | 139 | 81 | 47 | 164 | 92 | 63 | 105 | 108 | 170 | 3 | 135 | 101 | 121 | 68 | 6 | 111 | 65 | 147 | 150 | 122 | 7 | 84 | 46 |
| | 22 | 103 | 86 | 169 | 134 | 44 | 175 | 167 | 89 | 128 | 27 | 31 | 56 | 43 | 102 | 156 | 160 | 141 | 67 | 9 | 110 | 159 | 133 |
| | 78 | 154 | 176 | 174 | 5 | 82 | 11 | 25 | 80 | 130 | 163 | 88 | 36 | 166 | 137 | 104 | 48 | 129 | 87 | 95 | 55 | 49 | 145 |
| | 178 | 0 | 98 | 64 | 54 | 100 | 37 | 79 | 69 | 38 | 177 | 136 | 114 | 17 | 52 | 19 | 30 | 97 | 51 | 168 | 132 | 138 | 83 |
| | 76 | 13 | 18 | 115 | 71 | 91 | 179 | 112 | 155 | 15 | 14 | 26 | 60 | 29 | 116 | 66 | 120 | 142 | 152 | | | | |
| **12/15** | 91 | 19 | 11 | 106 | 14 | 40 | 20 | 67 | 32 | 22 | 31 | 23 | 78 | 68 | 79 | 141 | 117 | 95 | 88 | 136 | 52 | 121 | 1 |
| | 133 | 4 | 2 | 21 | 122 | 38 | 12 | 69 | 111 | 81 | 82 | 58 | 46 | 112 | 60 | 33 | 73 | 53 | 92 | 75 | 48 | 47 | 110 |
| | 80 | 76 | 138 | 87 | 85 | 65 | 130 | 57 | 102 | 83 | 64 | 86 | 100 | 39 | 49 | 125 | 108 | 119 | 6 | 118 | 35 | 61 | 71 |
| | 30 | 45 | 94 | 26 | 116 | 98 | 37 | 55 | 44 | 70 | 25 | 7 | 34 | 114 | 135 | 128 | 137 | 84 | 51 | 28 | 97 | 27 | 89 |
| | 29 | 62 | 50 | 139 | 56 | 109 | 77 | 59 | 127 | 142 | 96 | 105 | 99 | 90 | 13 | 124 | 120 | 115 | 126 | 143 | 149 | 74 | 41 |
| | 178 | 129 | 18 | 131 | 42 | 165 | 101 | 134 | 36 | 140 | 132 | 103 | 72 | 164 | 93 | 54 | 166 | 43 | 123 | 113 | 0 | 154 | 10 |
| | 63 | 107 | 162 | 157 | 66 | 104 | 17 | 147 | 167 | 174 | 179 | 3 | 173 | 160 | 155 | 161 | 152 | 156 | 177 | 24 | 170 | 9 | 159 |
| | 16 | 15 | 148 | 5 | 146 | 163 | 172 | 175 | 151 | 169 | 176 | 150 | 153 | 171 | 158 | 168 | 144 | 8 | 145 | | | | |
| **13/15** | 49 | 2 | 57 | 47 | 31 | 35 | 24 | 39 | 59 | 0 | 45 | 41 | 55 | 53 | 51 | 37 | 33 | 43 | 56 | 38 | 48 | 32 | 50 |
| | 23 | 34 | 54 | 1 | 36 | 44 | 52 | 40 | 58 | 122 | 46 | 42 | 30 | 3 | 75 | 73 | 65 | 145 | 71 | 79 | 67 | 69 | 83 |
| | 85 | 147 | 63 | 81 | 77 | 61 | 5 | 26 | 62 | 64 | 74 | 70 | 82 | 149 | 76 | 4 | 78 | 84 | 80 | 86 | 66 | 68 | 72 |
| | 6 | 60 | 154 | 103 | 95 | 101 | 143 | 9 | 89 | 141 | 128 | 97 | 137 | 133 | 7 | 13 | 99 | 91 | 93 | 87 | 11 | 136 | 90 |
| | 88 | 94 | 10 | 8 | 14 | 96 | 104 | 92 | 132 | 142 | 100 | 98 | 12 | 102 | 152 | 139 | 150 | 106 | 146 | 130 | 27 | 108 | 153 |
| | 112 | 114 | 29 | 110 | 134 | 116 | 15 | 127 | 125 | 123 | 120 | 148 | 151 | 113 | 126 | 124 | 135 | 129 | 109 | 25 | 28 | 158 | 117 |
| | 105 | 115 | 111 | 131 | 107 | 121 | 18 | 170 | 164 | 20 | 140 | 160 | 166 | 162 | 119 | 155 | 168 | 178 | 22 | 174 | 172 | 176 | 16 |
| | 157 | 159 | 171 | 161 | 118 | 17 | 163 | 21 | 165 | 19 | 179 | 177 | 167 | 138 | 173 | 156 | 144 | 169 | 175 | | | | |

**Table B.1.6** 4096QAM ($N_{inner}$ = 64800)

| Code Rate | Order of Group-Wise Interleaving π(j) (0 ≤ j < 180) | | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 |
| | 23 | 24 | 25 | 26 | 27 | 28 | 29 | 30 | 31 | 32 | 33 | 34 | 35 | 36 | 37 | 38 | 39 | 40 | 41 | 42 | 43 | 44 | 45 |
| | 46 | 47 | 48 | 49 | 50 | 51 | 52 | 53 | 54 | 55 | 56 | 57 | 58 | 59 | 60 | 61 | 62 | 63 | 64 | 65 | 66 | 67 | 68 |
| | 69 | 70 | 71 | 72 | 73 | 74 | 75 | 76 | 77 | 78 | 79 | 80 | 81 | 82 | 83 | 84 | 85 | 86 | 87 | 88 | 89 | 90 | 91 |
| | 92 | 93 | 94 | 95 | 96 | 97 | 98 | 99 | 100 | 101 | 102 | 103 | 104 | 105 | 106 | 107 | 108 | 109 | 110 | 111 | 112 | 113 | 114 |
| | 115 | 116 | 117 | 118 | 119 | 120 | 121 | 122 | 123 | 124 | 125 | 126 | 127 | 128 | 129 | 130 | 131 | 132 | 133 | 134 | 135 | 136 | 137 |
| | 138 | 139 | 140 | 141 | 142 | 143 | 144 | 145 | 146 | 147 | 148 | 149 | 150 | 151 | 152 | 153 | 154 | 155 | 156 | 157 | 158 | 159 | 160 |
| | 161 | 162 | 163 | 164 | 165 | 166 | 167 | 168 | 169 | 170 | 171 | 172 | 173 | 174 | 175 | 176 | 177 | 178 | 179 | | | | |
| 2/15 | 14 | 129 | 71 | 96 | 171 | 36 | 144 | 64 | 162 | 4 | 86 | 128 | 113 | 7 | 105 | 131 | 2 | 133 | 106 | 79 | 11 | 152 | 26 |
| | 118 | 158 | 126 | 17 | 55 | 45 | 111 | 138 | 84 | 6 | 52 | 167 | 38 | 20 | 101 | 31 | 120 | 5 | 112 | 74 | 69 | 121 | 9 |
| | 154 | 15 | 146 | 116 | 63 | 1 | 114 | 83 | 124 | 109 | 39 | 75 | 123 | 57 | 49 | 30 | 21 | 40 | 43 | 77 | 157 | 44 | 13 |
| | 99 | 34 | 147 | 166 | 56 | 155 | 176 | 95 | 102 | 119 | 161 | 37 | 159 | 97 | 68 | 122 | 163 | 89 | 61 | 107 | 22 | 10 | 127 |
| | 87 | 103 | 179 | 172 | 66 | 59 | 8 | 145 | 88 | 132 | 110 | 54 | 47 | 153 | 25 | 32 | 73 | 42 | 148 | 150 | 28 | 91 | 18 |
| | 24 | 19 | 53 | 136 | 48 | 76 | 35 | 151 | 173 | 149 | 142 | 160 | 94 | 117 | 169 | 165 | 141 | 80 | 67 | 170 | 164 | 82 | 65 |
| | 60 | 135 | 168 | 23 | 100 | 134 | 90 | 98 | 125 | 85 | 137 | 81 | 41 | 156 | 50 | 3 | 29 | 16 | 72 | 177 | 0 | 78 | 62 |
| | 139 | 93 | 46 | 12 | 175 | 130 | 51 | 178 | 92 | 115 | 174 | 27 | 70 | 58 | 33 | 104 | 140 | 108 | 143 | | | | |
| 3/15 | 136 | 20 | 44 | 36 | 17 | 120 | 89 | 142 | 66 | 35 | 42 | 116 | 14 | 119 | 117 | 29 | 47 | 125 | 11 | 158 | 74 | 25 | 37 |
| | 175 | 41 | 145 | 100 | 131 | 173 | 179 | 16 | 77 | 112 | 40 | 58 | 23 | 82 | 168 | 106 | 83 | 34 | 49 | 122 | 2 | 157 | 107 |
| | 79 | 137 | 53 | 96 | 33 | 70 | 19 | 38 | 121 | 90 | 118 | 126 | 165 | 109 | 154 | 140 | 10 | 178 | 143 | 92 | 63 | 176 | 146 |
| | 134 | 177 | 139 | 3 | 113 | 172 | 9 | 50 | 138 | 61 | 93 | 94 | 88 | 132 | 105 | 151 | 170 | 86 | 12 | 1 | 7 | 56 | 59 |
| | 101 | 155 | 95 | 54 | 85 | 13 | 39 | 15 | 76 | 130 | 97 | 110 | 174 | 72 | 150 | 55 | 73 | 99 | 111 | 162 | 26 | 21 | 156 |
| | 28 | 160 | 149 | 133 | 104 | 81 | 69 | 84 | 4 | 6 | 147 | 48 | 115 | 169 | 127 | 161 | 71 | 68 | 80 | 91 | 98 | 8 | 57 |
| | 171 | 135 | 52 | 5 | 141 | 65 | 75 | 163 | 43 | 144 | 167 | 159 | 129 | 46 | 31 | 30 | 166 | 0 | 148 | 128 | 102 | 103 | 60 |
| | 32 | 18 | 51 | 87 | 114 | 64 | 22 | 164 | 24 | 123 | 27 | 62 | 124 | 152 | 78 | 108 | 67 | 153 | 45 | | | | |
| 4/15 | 91 | 52 | 36 | 30 | 35 | 6 | 121 | 29 | 150 | 47 | 163 | 2 | 89 | 39 | 65 | 157 | 64 | 122 | 101 | 40 | 84 | 69 | 90 |
| | 129 | 10 | 9 | 15 | 162 | 21 | 171 | 43 | 44 | 132 | 158 | 104 | 4 | 72 | 169 | 177 | 103 | 76 | 28 | 78 | 53 | 1 | 151 |
| | 161 | 88 | 148 | 42 | 160 | 109 | 100 | 126 | 138 | 108 | 38 | 25 | 3 | 112 | 17 | 124 | 155 | 172 | 134 | 86 | 119 | 94 | 145 |
| | 178 | 68 | 26 | 130 | 140 | 115 | 152 | 139 | 37 | 22 | 102 | 14 | 118 | 11 | 98 | 154 | 61 | 146 | 164 | 107 | 131 | 159 | 63 |
| | 93 | 7 | 79 | 5 | 137 | 165 | 59 | 77 | 55 | 80 | 117 | 13 | 173 | 144 | 85 | 153 | 66 | 106 | 49 | 34 | 48 | 41 | 143 |
| | 142 | 27 | 136 | 18 | 111 | 175 | 123 | 147 | 114 | 19 | 125 | 166 | 149 | 113 | 46 | 31 | 141 | 120 | 57 | 74 | 8 | 20 | 96 |
| | 170 | 128 | 97 | 16 | 60 | 110 | 156 | 45 | 82 | 105 | 62 | 99 | 23 | 92 | 32 | 50 | 73 | 56 | 167 | 95 | 24 | 168 | 33 |
| | 116 | 75 | 127 | 81 | 67 | 179 | 174 | 70 | 12 | 58 | 87 | 176 | 0 | 51 | 135 | 83 | 133 | 54 | 71 | | | | |
| 5/15 | 146 | 89 | 57 | 16 | 164 | 138 | 91 | 78 | 90 | 66 | 122 | 12 | 9 | 157 | 14 | 68 | 112 | 128 | 74 | 45 | 28 | 87 | 158 |
| | 56 | 61 | 168 | 18 | 161 | 95 | 99 | 139 | 22 | 65 | 130 | 166 | 118 | 150 | 49 | 142 | 44 | 36 | 1 | 121 | 6 | 46 | 29 |
| | 88 | 47 | 0 | 58 | 105 | 43 | 80 | 64 | 107 | 21 | 55 | 151 | 8 | 145 | 163 | 7 | 98 | 123 | 17 | 11 | 153 | 136 | 52 |
| | 3 | 13 | 34 | 160 | 102 | 125 | 114 | 152 | 84 | 32 | 97 | 33 | 60 | 62 | 79 | 37 | 129 | 38 | 165 | 71 | 75 | 59 | 144 |
| | 127 | 132 | 104 | 53 | 162 | 103 | 120 | 54 | 155 | 116 | 48 | 77 | 76 | 73 | 113 | 119 | 179 | 177 | 41 | 19 | 92 | 109 | 31 |
| | 143 | 178 | 108 | 39 | 140 | 106 | 40 | 5 | 25 | 81 | 176 | 101 | 124 | 126 | 72 | 111 | 4 | 173 | 156 | 134 | 86 | 174 | 2 |
| | 170 | 35 | 175 | 137 | 15 | 24 | 69 | 96 | 30 | 117 | 67 | 171 | 149 | 169 | 63 | 23 | 20 | 167 | 27 | 147 | 51 | 10 | 82 |
| | 131 | 85 | 110 | 94 | 135 | 172 | 148 | 50 | 154 | 42 | 70 | 115 | 26 | 83 | 141 | 100 | 133 | 93 | 159 | | | | |
| 6/15 | 66 | 21 | 51 | 55 | 117 | 24 | 33 | 12 | 70 | 63 | 47 | 65 | 145 | 8 | 0 | 57 | 23 | 71 | 59 | 14 | 40 | 42 | 15 |
| | 56 | 2 | 43 | 64 | 58 | 67 | 53 | 68 | 61 | 39 | 52 | 69 | 1 | 22 | 31 | 161 | 38 | 30 | 19 | 17 | 18 | 4 | 41 |
| | 25 | 44 | 136 | 29 | 36 | 26 | 126 | 177 | 62 | 37 | 148 | 9 | 13 | 45 | 46 | 152 | 50 | 49 | 27 | 77 | 60 | 35 | 48 |
| | 178 | 28 | 34 | 106 | 127 | 76 | 131 | 105 | 138 | 75 | 130 | 101 | 167 | 54 | 173 | 113 | 108 | 92 | 135 | 124 | 121 | 97 | 149 |
| | 143 | 81 | 32 | 96 | 3 | 78 | 107 | 86 | 98 | 16 | 162 | 150 | 111 | 158 | 172 | 139 | 74 | 142 | 166 | 7 | 5 | 119 | 20 |
| | 144 | 151 | 90 | 11 | 156 | 100 | 175 | 83 | 155 | 159 | 128 | 88 | 87 | 93 | 103 | 94 | 140 | 165 | 6 | 137 | 157 | 10 | 85 |
| | 141 | 129 | 146 | 122 | 73 | 112 | 132 | 125 | 174 | 169 | 168 | 79 | 84 | 118 | 179 | 147 | 91 | 160 | 163 | 115 | 89 | 80 | 102 |
| | 104 | 134 | 82 | 95 | 133 | 164 | 154 | 120 | 110 | 170 | 114 | 153 | 72 | 109 | 171 | 176 | 99 | 116 | 123 | | | | |
| 7/15 | 59 | 122 | 161 | 93 | 37 | 112 | 111 | 62 | 42 | 102 | 119 | 72 | 60 | 144 | 34 | 120 | 46 | 31 | 129 | 172 | 149 | 94 | 65 |
| | 9 | 0 | 76 | 13 | 61 | 3 | 70 | 40 | 78 | 127 | 35 | 145 | 28 | 48 | 162 | 92 | 73 | 6 | 134 | 66 | 160 | 133 | 101 |
| | 4 | 5 | 87 | 106 | 79 | 104 | 168 | 163 | 170 | 57 | 83 | 44 | 54 | 110 | 30 | 50 | 82 | 10 | 148 | 98 | 41 | 22 | 96 |
| | 49 | 90 | 100 | 29 | 39 | 175 | 38 | 109 | 91 | 74 | 159 | 139 | 177 | 71 | 47 | 146 | 63 | 86 | 45 | 123 | 33 | 138 | 51 |

| | | | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 89 | 88 | 167 | 80 | 142 | 108 | 69 | 7 | 103 | 115 | 99 | 135 | 36 | 11 | 166 | 169 | 8 | 165 | 68 | 173 | 140 | 95 | 179 |
| | 2 | 125 | 105 | 1 | 116 | 150 | 174 | 15 | 75 | 64 | 176 | 81 | 55 | 130 | 151 | 156 | 53 | 171 | 16 | 113 | 24 | 117 | 154 |
| | 157 | 164 | 143 | 12 | 56 | 152 | 20 | 85 | 84 | 77 | 158 | 107 | 32 | 153 | 147 | 132 | 124 | 52 | 121 | 58 | 118 | 137 | 114 |
| | 97 | 19 | 155 | 67 | 25 | 17 | 126 | 23 | 43 | 27 | 21 | 136 | 131 | 26 | 14 | 18 | 128 | 141 | 178 | | | | |
| **8/15** | 77 | 48 | 82 | 51 | 57 | 69 | 65 | 6 | 71 | 90 | 84 | 81 | 50 | 88 | 61 | 55 | 53 | 73 | 39 | 13 | 79 | 75 | 41 |
| | 18 | 38 | 89 | 49 | 93 | 36 | 64 | 47 | 40 | 42 | 76 | 70 | 56 | 3 | 72 | 2 | 54 | 52 | 145 | 19 | 78 | 80 | 63 |
| | 87 | 67 | 86 | 10 | 1 | 58 | 17 | 14 | 175 | 91 | 68 | 85 | 94 | 15 | 43 | 74 | 60 | 66 | 37 | 92 | 4 | 9 | 16 |
| | 83 | 46 | 44 | 102 | 30 | 112 | 122 | 110 | 29 | 20 | 105 | 138 | 101 | 174 | 33 | 137 | 136 | 131 | 166 | 59 | 34 | 62 | 125 |
| | 28 | 26 | 45 | 24 | 23 | 21 | 157 | 98 | 35 | 95 | 22 | 32 | 103 | 27 | 113 | 31 | 119 | 173 | 168 | 118 | 120 | 114 | 149 |
| | 159 | 155 | 179 | 160 | 161 | 130 | 123 | 172 | 139 | 124 | 153 | 0 | 109 | 167 | 128 | 107 | 117 | 147 | 177 | 96 | 164 | 152 | 11 |
| | 148 | 158 | 129 | 163 | 176 | 151 | 171 | 8 | 106 | 144 | 150 | 169 | 108 | 162 | 143 | 111 | 141 | 133 | 178 | 134 | 146 | 99 | 132 |
| | 142 | 104 | 115 | 135 | 121 | 100 | 12 | 170 | 156 | 126 | 5 | 127 | 154 | 97 | 140 | 116 | 165 | 7 | 25 | | | | |
| **9/15** | 67 | 79 | 72 | 175 | 1 | 92 | 63 | 65 | 36 | 73 | 18 | 3 | 43 | 78 | 5 | 40 | 82 | 20 | 15 | 76 | 28 | 84 | 59 |
| | 91 | 93 | 54 | 58 | 60 | 2 | 19 | 66 | 44 | 85 | 48 | 0 | 50 | 166 | 89 | 41 | 24 | 83 | 75 | 55 | 64 | 52 | 98 |
| | 39 | 141 | 34 | 74 | 33 | 45 | 99 | 46 | 10 | 69 | 94 | 101 | 56 | 9 | 97 | 96 | 37 | 14 | 31 | 70 | 106 | 113 | 80 |
| | 62 | 100 | 13 | 32 | 88 | 57 | 127 | 53 | 68 | 146 | 61 | 7 | 107 | 71 | 51 | 161 | 81 | 49 | 86 | 95 | 103 | 30 | 25 |
| | 126 | 87 | 22 | 47 | 27 | 171 | 102 | 6 | 132 | 77 | 90 | 38 | 167 | 4 | 35 | 26 | 118 | 140 | 104 | 128 | 179 | 124 | 109 |
| | 159 | 42 | 110 | 21 | 105 | 148 | 142 | 134 | 23 | 117 | 122 | 160 | 12 | 154 | 114 | 156 | 151 | 145 | 169 | 11 | 139 | 177 | 129 |
| | 155 | 178 | 138 | 176 | 147 | 121 | 136 | 165 | 170 | 133 | 149 | 150 | 174 | 168 | 125 | 116 | 115 | 164 | 29 | 119 | 153 | 157 | 162 |
| | 173 | 112 | 144 | 172 | 123 | 137 | 16 | 120 | 131 | 111 | 135 | 163 | 17 | 130 | 152 | 108 | 8 | 158 | 143 | | | | |
| **10/15** | 36 | 21 | 117 | 71 | 38 | 108 | 42 | 61 | 13 | 88 | 97 | 68 | 2 | 67 | 50 | 64 | 95 | 63 | 100 | 9 | 82 | 51 | 45 |
| | 78 | 31 | 18 | 103 | 39 | 119 | 25 | 40 | 28 | 72 | 11 | 73 | 86 | 131 | 84 | 111 | 24 | 58 | 60 | 81 | 37 | 89 | 1 |
| | 93 | 56 | 69 | 96 | 35 | 57 | 116 | 130 | 55 | 74 | 41 | 169 | 54 | 14 | 26 | 65 | 83 | 165 | 107 | 0 | 52 | 144 | 75 |
| | 101 | 8 | 115 | 118 | 85 | 48 | 112 | 80 | 90 | 32 | 173 | 76 | 33 | 16 | 77 | 164 | 104 | 46 | 20 | 98 | 109 | 29 | 114 |
| | 7 | 110 | 99 | 53 | 133 | 70 | 87 | 106 | 145 | 4 | 113 | 27 | 59 | 34 | 5 | 102 | 148 | 142 | 79 | 19 | 44 | 159 | 174 |
| | 155 | 136 | 94 | 43 | 49 | 152 | 161 | 66 | 3 | 121 | 135 | 147 | 17 | 157 | 30 | 153 | 154 | 137 | 168 | 92 | 149 | 171 | 10 |
| | 177 | 134 | 143 | 176 | 179 | 105 | 172 | 47 | 146 | 160 | 23 | 175 | 141 | 91 | 140 | 163 | 132 | 6 | 126 | 124 | 12 | 170 | 167 |
| | 151 | 125 | 139 | 150 | 15 | 129 | 162 | 120 | 166 | 156 | 62 | 158 | 178 | 128 | 127 | 22 | 122 | 123 | 138 | | | | |
| **11/15** | 77 | 97 | 3 | 44 | 119 | 72 | 83 | 116 | 40 | 0 | 111 | 8 | 68 | 43 | 24 | 102 | 49 | 92 | 65 | 31 | 93 | 60 | 17 |
| | 76 | 89 | 118 | 70 | 87 | 15 | 67 | 22 | 59 | 95 | 46 | 38 | 125 | 48 | 58 | 140 | 104 | 73 | 47 | 14 | 120 | 1 | 50 |
| | 80 | 63 | 62 | 45 | 9 | 25 | 114 | 19 | 82 | 54 | 150 | 121 | 130 | 123 | 37 | 55 | 23 | 98 | 81 | 122 | 103 | 85 | 126 |
| | 101 | 78 | 5 | 128 | 148 | 57 | 12 | 107 | 36 | 2 | 109 | 52 | 39 | 66 | 115 | 42 | 156 | 90 | 51 | 91 | 29 | 84 | 18 |
| | 144 | 10 | 94 | 64 | 100 | 86 | 71 | 27 | 30 | 32 | 110 | 33 | 113 | 131 | 35 | 34 | 112 | 26 | 108 | 16 | 61 | 56 | 75 |
| | 41 | 117 | 69 | 172 | 96 | 149 | 127 | 124 | 173 | 13 | 74 | 105 | 53 | 161 | 146 | 174 | 79 | 88 | 28 | 129 | 134 | 139 | 136 |
| | 145 | 170 | 135 | 158 | 154 | 162 | 7 | 169 | 99 | 106 | 137 | 165 | 143 | 4 | 175 | 138 | 133 | 171 | 168 | 147 | 167 | 141 | 163 |
| | 176 | 179 | 142 | 11 | 177 | 153 | 151 | 159 | 132 | 20 | 164 | 6 | 157 | 178 | 21 | 166 | 155 | 160 | 152 | | | | |
| **12/15** | 110 | 16 | 64 | 100 | 55 | 70 | 48 | 26 | 60 | 71 | 93 | 1 | 59 | 88 | 97 | 136 | 67 | 94 | 90 | 72 | 49 | 23 | 41 |
| | 92 | 9 | 35 | 37 | 113 | 101 | 111 | 8 | 52 | 56 | 19 | 134 | 151 | 84 | 126 | 159 | 63 | 44 | 65 | 139 | 31 | 57 | 103 |
| | 22 | 116 | 172 | 38 | 95 | 36 | 46 | 141 | 114 | 4 | 106 | 149 | 85 | 86 | 66 | 51 | 121 | 105 | 109 | 87 | 6 | 135 | 127 |
| | 47 | 123 | 39 | 10 | 148 | 43 | 131 | 147 | 45 | 143 | 5 | 108 | 81 | 2 | 140 | 120 | 132 | 76 | 58 | 137 | 18 | 29 | 125 |
| | 17 | 30 | 32 | 156 | 133 | 78 | 91 | 161 | 104 | 174 | 53 | 61 | 50 | 74 | 77 | 33 | 171 | 138 | 28 | 69 | 112 | 119 | 12 |
| | 102 | 20 | 167 | 99 | 122 | 117 | 24 | 98 | 115 | 124 | 42 | 7 | 79 | 75 | 128 | 82 | 68 | 80 | 3 | 11 | 54 | 96 | 40 |
| | 129 | 142 | 107 | 73 | 175 | 14 | 83 | 150 | 165 | 118 | 89 | 130 | 15 | 163 | 34 | 166 | 173 | 146 | 168 | 153 | 154 | 177 | 62 |
| | 145 | 0 | 178 | 155 | 157 | 179 | 144 | 158 | 152 | 13 | 25 | 176 | 162 | 169 | 164 | 27 | 21 | 160 | 170 | | | | |
| **13/15** | 87 | 50 | 6 | 42 | 82 | 54 | 96 | 0 | 62 | 124 | 109 | 126 | 23 | 64 | 53 | 20 | 41 | 111 | 145 | 135 | 68 | 2 | 122 |
| | 128 | 107 | 7 | 28 | 14 | 125 | 136 | 154 | 10 | 92 | 99 | 84 | 86 | 151 | 108 | 24 | 94 | 148 | 29 | 123 | 13 | 88 | 52 |
| | 35 | 61 | 102 | 132 | 95 | 70 | 40 | 129 | 101 | 36 | 51 | 150 | 142 | 152 | 121 | 131 | 116 | 97 | 104 | 31 | 59 | 137 | 83 |
| | 112 | 113 | 57 | 77 | 32 | 93 | 49 | 58 | 117 | 78 | 1 | 149 | 37 | 11 | 100 | 85 | 79 | 72 | 66 | 130 | 18 | 63 | 55 |
| | 91 | 46 | 146 | 21 | 143 | 44 | 110 | 75 | 138 | 16 | 76 | 45 | 114 | 144 | 119 | 38 | 140 | 65 | 30 | 133 | 153 | 33 | 89 |
| | 71 | 115 | 105 | 90 | 56 | 25 | 103 | 147 | 73 | 60 | 47 | 118 | 27 | 69 | 9 | 74 | 48 | 19 | 39 | 43 | 34 | 81 | 139 |
| | 3 | 164 | 106 | 134 | 5 | 67 | 80 | 141 | 120 | 98 | 155 | 8 | 156 | 162 | 163 | 165 | 26 | 161 | 168 | 176 | 159 | 170 | 4 |
| | 127 | 22 | 173 | 157 | 171 | 178 | 158 | 17 | 174 | 179 | 167 | 12 | 172 | 166 | 160 | 177 | 169 | 175 | 15 | | | | |

## B.2 PERMUTATION SEQUENCES OF GROUP-WISE INTERLEAVING FOR $N_{INNER}$ = 16200 ($N_{GROUP}$ = 45)

**Table B.2.1** QPSK ($N_{inner}$ = 16200)

| Code Rate | Order of Group-Wise Interleaving $\pi(j)$ $(0 \le j < 45)$ | | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 |
| | 23 | 24 | 25 | 26 | 27 | 28 | 29 | 30 | 31 | 32 | 33 | 34 | 35 | 36 | 37 | 38 | 39 | 40 | 41 | 42 | 43 | 44 | |
| 2/15 | 0 | 2 | 4 | 6 | 8 | 10 | 12 | 14 | 16 | 18 | 20 | 22 | 24 | 26 | 28 | 30 | 32 | 34 | 36 | 38 | 40 | 42 | 1 |
| | 3 | 5 | 7 | 9 | 11 | 13 | 15 | 17 | 19 | 21 | 23 | 25 | 27 | 29 | 31 | 33 | 35 | 37 | 39 | 41 | 43 | 44 | |
| 3/15 | 15 | 22 | 34 | 19 | 7 | 17 | 28 | 43 | 30 | 32 | 14 | 1 | 11 | 0 | 3 | 9 | 10 | 38 | 24 | 4 | 23 | 18 | 27 |
| | 39 | 29 | 33 | 8 | 2 | 40 | 21 | 20 | 36 | 44 | 12 | 37 | 13 | 35 | 6 | 31 | 26 | 16 | 25 | 42 | 5 | 41 | |
| 4/15 | 0 | 2 | 4 | 6 | 8 | 10 | 12 | 14 | 16 | 18 | 20 | 22 | 24 | 26 | 28 | 30 | 32 | 34 | 36 | 38 | 40 | 42 | 1 |
| | 3 | 5 | 7 | 9 | 11 | 13 | 15 | 17 | 19 | 21 | 23 | 25 | 27 | 29 | 31 | 33 | 35 | 37 | 39 | 41 | 43 | 44 | |
| 5/15 | 35 | 7 | 29 | 11 | 14 | 32 | 38 | 28 | 20 | 17 | 25 | 39 | 19 | 4 | 1 | 12 | 10 | 30 | 0 | 44 | 43 | 2 | 21 |
| | 5 | 13 | 34 | 37 | 23 | 15 | 36 | 18 | 42 | 16 | 33 | 31 | 27 | 22 | 3 | 6 | 40 | 24 | 41 | 9 | 26 | 8 | |
| 6/15 | 7 | 4 | 0 | 5 | 27 | 30 | 25 | 13 | 31 | 9 | 34 | 10 | 17 | 11 | 8 | 12 | 15 | 16 | 18 | 19 | 20 | 21 | 22 |
| | 23 | 1 | 35 | 24 | 29 | 33 | 6 | 26 | 14 | 32 | 28 | 2 | 3 | 36 | 37 | 38 | 39 | 40 | 41 | 42 | 43 | 44 | |
| 7/15 | 3 | 7 | 1 | 4 | 18 | 21 | 22 | 6 | 9 | 5 | 17 | 14 | 13 | 15 | 10 | 20 | 8 | 19 | 16 | 12 | 0 | 11 | 2 |
| | 23 | 24 | 25 | 26 | 27 | 28 | 29 | 30 | 31 | 32 | 33 | 34 | 35 | 36 | 37 | 38 | 39 | 40 | 41 | 42 | 43 | 44 | |
| 8/15 | 0 | 2 | 4 | 6 | 8 | 10 | 12 | 14 | 16 | 18 | 20 | 22 | 24 | 26 | 28 | 30 | 32 | 34 | 36 | 38 | 40 | 42 | 1 |
| | 3 | 5 | 7 | 9 | 11 | 13 | 15 | 17 | 19 | 21 | 23 | 25 | 27 | 29 | 31 | 33 | 35 | 37 | 39 | 41 | 43 | 44 | |
| 9/15 | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 |
| | 23 | 24 | 25 | 26 | 27 | 28 | 29 | 30 | 31 | 32 | 33 | 34 | 35 | 36 | 37 | 38 | 39 | 40 | 41 | 42 | 43 | 44 | |
| 10/15 | 1 | 4 | 5 | 6 | 24 | 21 | 18 | 7 | 17 | 12 | 8 | 20 | 23 | 29 | 28 | 30 | 32 | 34 | 36 | 38 | 40 | 42 | 0 |
| | 2 | 3 | 14 | 22 | 13 | 10 | 25 | 9 | 27 | 19 | 16 | 15 | 26 | 11 | 31 | 33 | 35 | 37 | 39 | 41 | 43 | 44 | |
| 11/15 | 0 | 2 | 4 | 6 | 8 | 10 | 12 | 14 | 16 | 18 | 20 | 22 | 24 | 26 | 28 | 30 | 32 | 34 | 36 | 38 | 40 | 42 | 1 |
| | 3 | 5 | 7 | 9 | 11 | 13 | 15 | 17 | 19 | 21 | 23 | 25 | 27 | 29 | 31 | 33 | 35 | 37 | 39 | 41 | 43 | 44 | |
| 12/15 | 0 | 2 | 4 | 6 | 8 | 10 | 12 | 14 | 16 | 18 | 20 | 22 | 24 | 26 | 28 | 30 | 32 | 34 | 36 | 38 | 40 | 42 | 1 |
| | 3 | 5 | 7 | 9 | 11 | 13 | 15 | 17 | 19 | 21 | 23 | 25 | 27 | 29 | 31 | 33 | 35 | 37 | 39 | 41 | 43 | 44 | |
| 13/15 | 26 | 10 | 12 | 38 | 28 | 15 | 0 | 44 | 34 | 24 | 14 | 8 | 40 | 30 | 20 | 13 | 42 | 32 | 22 | 11 | 9 | 36 | 25 |
| | 7 | 5 | 37 | 27 | 4 | 16 | 43 | 33 | 23 | 2 | 18 | 39 | 29 | 19 | 6 | 41 | 31 | 21 | 3 | 17 | 35 | 1 | |

**Table B.2.2** 16QAM (Code length = 16200 bits)

| Code Rate | Order of Group-Wise Interleaving $\pi(j)$ $(0 \le j < 45)$ | | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 |
| | 23 | 24 | 25 | 26 | 27 | 28 | 29 | 30 | 31 | 32 | 33 | 34 | 35 | 36 | 37 | 38 | 39 | 40 | 41 | 42 | 43 | 44 | |
| 2/15 | 5 | 33 | 18 | 8 | 29 | 10 | 21 | 14 | 30 | 26 | 11 | 23 | 27 | 4 | 7 | 6 | 24 | 44 | 38 | 31 | 34 | 43 | 13 |
| | 0 | 15 | 42 | 17 | 2 | 20 | 12 | 40 | 39 | 35 | 32 | 1 | 3 | 41 | 37 | 9 | 25 | 19 | 22 | 16 | 28 | 36 | |
| 3/15 | 18 | 16 | 5 | 29 | 26 | 43 | 23 | 6 | 1 | 24 | 7 | 19 | 37 | 2 | 27 | 3 | 10 | 15 | 36 | 39 | 22 | 12 | 35 |
| | 33 | 4 | 17 | 30 | 31 | 21 | 9 | 11 | 41 | 0 | 32 | 20 | 40 | 25 | 8 | 34 | 38 | 28 | 14 | 44 | 13 | 42 | |
| 4/15 | 34 | 3 | 19 | 35 | 25 | 2 | 17 | 36 | 26 | 38 | 0 | 40 | 27 | 10 | 7 | 43 | 21 | 28 | 15 | 6 | 1 | 37 | 18 |
| | 30 | 32 | 33 | 29 | 22 | 12 | 13 | 5 | 23 | 44 | 14 | 4 | 31 | 20 | 39 | 42 | 11 | 9 | 16 | 41 | 8 | 24 | |
| 5/15 | 3 | 33 | 39 | 2 | 38 | 29 | 0 | 10 | 25 | 17 | 7 | 21 | 44 | 37 | 8 | 34 | 20 | 1 | 4 | 31 | 11 | 42 | 22 |
| | 13 | 12 | 28 | 26 | 43 | 30 | 14 | 16 | 23 | 24 | 15 | 5 | 18 | 9 | 36 | 6 | 19 | 32 | 40 | 41 | 35 | 27 | |
| 6/15 | 12 | 13 | 15 | 30 | 27 | 25 | 11 | 34 | 9 | 4 | 31 | 22 | 6 | 32 | 7 | 21 | 17 | 3 | 1 | 26 | 10 | 33 | 19 |
| | 2 | 18 | 5 | 28 | 35 | 8 | 16 | 29 | 23 | 14 | 0 | 20 | 24 | 36 | 37 | 38 | 39 | 40 | 41 | 42 | 43 | 44 | |
| 7/15 | 19 | 3 | 32 | 38 | 16 | 17 | 29 | 33 | 14 | 10 | 6 | 2 | 20 | 15 | 40 | 39 | 12 | 22 | 23 | 34 | 31 | 13 | 44 |
| | 43 | 36 | 24 | 37 | 42 | 0 | 9 | 4 | 21 | 5 | 35 | 26 | 41 | 7 | 28 | 11 | 25 | 8 | 18 | 1 | 30 | 27 | |
| 8/15 | 36 | 5 | 22 | 26 | 1 | 13 | 3 | 33 | 9 | 6 | 23 | 20 | 35 | 10 | 17 | 41 | 30 | 15 | 21 | 42 | 29 | 11 | 37 |
| | 4 | 2 | 38 | 44 | 0 | 18 | 19 | 8 | 31 | 28 | 43 | 14 | 34 | 32 | 25 | 40 | 12 | 16 | 24 | 39 | 27 | 7 | |
| 9/15 | 4 | 6 | 19 | 2 | 5 | 30 | 20 | 11 | 22 | 12 | 15 | 0 | 36 | 37 | 38 | 39 | 26 | 14 | 34 | 35 | 16 | 13 | 18 |
| | 42 | 7 | 10 | 25 | 43 | 40 | 17 | 41 | 24 | 33 | 31 | 23 | 32 | 21 | 3 | 27 | 28 | 8 | 9 | 29 | 1 | 44 | |
| 10/15 | 27 | 11 | 20 | 1 | 7 | 5 | 29 | 35 | 9 | 10 | 34 | 18 | 25 | 28 | 6 | 13 | 17 | 0 | 23 | 16 | 41 | 15 | 19 |
| | 44 | 24 | 37 | 4 | 31 | 8 | 32 | 14 | 42 | 12 | 2 | 40 | 30 | 36 | 39 | 43 | 21 | 3 | 22 | 26 | 33 | 38 | |
| 11/15 | 2 | 4 | 41 | 8 | 13 | 7 | 0 | 24 | 3 | 22 | 5 | 32 | 10 | 9 | 36 | 37 | 29 | 11 | 25 | 16 | 20 | 21 | 35 |
| | 34 | 15 | 1 | 6 | 14 | 27 | 30 | 33 | 12 | 17 | 28 | 23 | 40 | 26 | 31 | 38 | 39 | 18 | 19 | 42 | 43 | 44 | |
| 12/15 | 3 | 6 | 7 | 27 | 2 | 23 | 10 | 30 | 22 | 28 | 24 | 20 | 37 | 21 | 4 | 14 | 11 | 42 | 16 | 9 | 15 | 26 | 33 |
| | 40 | 5 | 8 | 44 | 34 | 18 | 0 | 32 | 29 | 19 | 41 | 38 | 17 | 25 | 43 | 35 | 36 | 13 | 39 | 12 | 1 | 31 | |
| 13/15 | 12 | 7 | 20 | 43 | 29 | 13 | 32 | 30 | 25 | 0 | 17 | 18 | 9 | 1 | 41 | 42 | 6 | 33 | 28 | 14 | 16 | 11 | 39 |
| | 40 | 15 | 4 | 23 | 5 | 2 | 24 | 22 | 38 | 10 | 8 | 19 | 34 | 26 | 36 | 37 | 27 | 21 | 31 | 3 | 35 | 44 | |

**Table B.2.3** 64QAM ($N_{inner}$ = 16200)

| Code Rate | Order of Group-Wise Interleaving π(j) (0 ≤ j < 45) | | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 |
| | 23 | 24 | 25 | 26 | 27 | 28 | 29 | 30 | 31 | 32 | 33 | 34 | 35 | 36 | 37 | 38 | 39 | 40 | 41 | 42 | 43 | 44 | |
| 2/15 | 7 | 11 | 4 | 38 | 19 | 25 | 2 | 43 | 15 | 26 | 18 | 14 | 9 | 29 | 44 | 32 | 0 | 5 | 35 | 10 | 1 | 12 | 6 |
| | 36 | 21 | 33 | 37 | 34 | 3 | 31 | 20 | 16 | 40 | 23 | 41 | 22 | 30 | 39 | 13 | 24 | 17 | 42 | 28 | 8 | 27 | |
| 3/15 | 19 | 34 | 22 | 6 | 29 | 25 | 23 | 36 | 7 | 8 | 24 | 16 | 27 | 43 | 11 | 35 | 5 | 28 | 13 | 4 | 3 | 17 | 15 |
| | 38 | 20 | 0 | 26 | 12 | 1 | 39 | 31 | 41 | 44 | 30 | 9 | 21 | 42 | 18 | 14 | 32 | 10 | 2 | 37 | 33 | 40 | |
| 4/15 | 41 | 34 | 32 | 37 | 5 | 8 | 13 | 15 | 30 | 31 | 22 | 25 | 42 | 20 | 23 | 17 | 1 | 40 | 44 | 12 | 6 | 43 | 7 |
| | 29 | 33 | 16 | 11 | 0 | 35 | 4 | 14 | 28 | 21 | 3 | 24 | 19 | 18 | 36 | 10 | 38 | 26 | 2 | 39 | 27 | 9 | |
| 5/15 | 25 | 44 | 8 | 39 | 37 | 2 | 11 | 7 | 0 | 12 | 4 | 31 | 33 | 38 | 43 | 21 | 26 | 13 | 28 | 29 | 1 | 27 | 18 |
| | 17 | 34 | 3 | 42 | 10 | 19 | 20 | 32 | 36 | 40 | 9 | 41 | 5 | 35 | 30 | 22 | 15 | 16 | 6 | 24 | 23 | 14 | |
| 6/15 | 31 | 12 | 39 | 32 | 30 | 24 | 28 | 15 | 38 | 23 | 27 | 41 | 0 | 6 | 17 | 37 | 42 | 20 | 11 | 4 | 40 | 2 | 3 |
| | 26 | 10 | 7 | 13 | 25 | 1 | 18 | 8 | 5 | 14 | 36 | 35 | 33 | 22 | 9 | 44 | 16 | 34 | 19 | 21 | 29 | 43 | |
| 7/15 | 2 | 14 | 10 | 0 | 37 | 42 | 38 | 40 | 24 | 29 | 28 | 35 | 18 | 16 | 20 | 27 | 41 | 30 | 15 | 19 | 9 | 43 | 25 |
| | 3 | 6 | 7 | 31 | 32 | 26 | 36 | 17 | 1 | 13 | 5 | 39 | 33 | 4 | 8 | 23 | 22 | 11 | 34 | 44 | 12 | 21 | |
| 8/15 | 36 | 6 | 2 | 20 | 43 | 17 | 33 | 22 | 23 | 25 | 13 | 0 | 10 | 7 | 21 | 1 | 19 | 26 | 8 | 14 | 31 | 35 | 16 |
| | 5 | 29 | 40 | 11 | 9 | 4 | 34 | 15 | 42 | 32 | 28 | 18 | 37 | 30 | 39 | 24 | 41 | 3 | 38 | 27 | 12 | 44 | |
| 9/15 | 21 | 5 | 43 | 38 | 40 | 1 | 3 | 17 | 11 | 37 | 10 | 41 | 9 | 15 | 25 | 44 | 14 | 27 | 7 | 18 | 20 | 35 | 16 |
| | 0 | 6 | 19 | 8 | 22 | 29 | 28 | 34 | 31 | 33 | 30 | 32 | 42 | 13 | 4 | 24 | 26 | 36 | 2 | 23 | 12 | 39 | |
| 10/15 | 14 | 22 | 18 | 11 | 28 | 26 | 2 | 38 | 10 | 0 | 5 | 12 | 24 | 17 | 29 | 16 | 39 | 13 | 23 | 8 | 25 | 43 | 34 |
| | 33 | 27 | 15 | 7 | 1 | 9 | 35 | 40 | 32 | 30 | 20 | 36 | 31 | 21 | 41 | 44 | 3 | 42 | 6 | 19 | 37 | 4 | |
| 11/15 | 31 | 20 | 21 | 25 | 4 | 16 | 9 | 3 | 17 | 24 | 5 | 10 | 12 | 28 | 6 | 19 | 8 | 15 | 13 | 11 | 29 | 22 | 27 |
| | 14 | 23 | 34 | 26 | 18 | 42 | 2 | 37 | 44 | 39 | 33 | 35 | 41 | 0 | 36 | 7 | 40 | 38 | 1 | 30 | 32 | 43 | |
| 12/15 | 17 | 11 | 14 | 7 | 31 | 10 | 2 | 26 | 0 | 32 | 29 | 22 | 33 | 12 | 20 | 28 | 27 | 39 | 37 | 15 | 4 | 5 | 8 |
| | 13 | 38 | 18 | 23 | 34 | 24 | 6 | 1 | 9 | 16 | 44 | 21 | 3 | 36 | 30 | 40 | 35 | 43 | 42 | 25 | 19 | 41 | |
| 13/15 | 9 | 7 | 15 | 10 | 11 | 12 | 13 | 6 | 21 | 17 | 14 | 20 | 26 | 8 | 25 | 32 | 34 | 23 | 2 | 4 | 31 | 18 | 5 |
| | 27 | 29 | 3 | 38 | 36 | 39 | 43 | 41 | 42 | 40 | 44 | 1 | 28 | 33 | 22 | 16 | 19 | 24 | 0 | 30 | 35 | 37 | |

**Table B.2.4** 256QAM ($N_{inner}$ = 16200)

| Code Rate | Order of Group-Wise Interleaving π(j) (0 ≤ j < 45) | | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 |
| | 23 | 24 | 25 | 26 | 27 | 28 | 29 | 30 | 31 | 32 | 33 | 34 | 35 | 36 | 37 | 38 | 39 | 40 | 41 | 42 | 43 | 44 | |
| 2/15 | 31 | 3 | 38 | 9 | 34 | 6 | 4 | 18 | 15 | 1 | 21 | 19 | 42 | 20 | 12 | 13 | 30 | 26 | 14 | 2 | 10 | 35 | 28 |
| | 44 | 23 | 11 | 22 | 16 | 29 | 40 | 27 | 37 | 25 | 41 | 5 | 43 | 39 | 36 | 7 | 24 | 32 | 17 | 33 | 8 | 0 | |
| 3/15 | 5 | 22 | 23 | 26 | 29 | 27 | 16 | 1 | 4 | 25 | 41 | 21 | 12 | 2 | 6 | 8 | 7 | 19 | 44 | 42 | 39 | 40 | 43 |
| | 35 | 10 | 28 | 13 | 15 | 37 | 32 | 3 | 24 | 36 | 38 | 11 | 18 | 33 | 30 | 14 | 9 | 34 | 20 | 0 | 17 | 31 | |
| 4/15 | 38 | 20 | 0 | 34 | 33 | 41 | 14 | 30 | 44 | 7 | 37 | 8 | 4 | 9 | 43 | 15 | 19 | 32 | 23 | 5 | 22 | 26 | 10 |
| | 12 | 3 | 31 | 36 | 21 | 24 | 11 | 16 | 18 | 17 | 29 | 35 | 42 | 13 | 40 | 1 | 28 | 2 | 25 | 6 | 39 | 27 | |
| 5/15 | 4 | 23 | 3 | 6 | 18 | 5 | 0 | 2 | 7 | 26 | 21 | 27 | 39 | 42 | 38 | 31 | 1 | 34 | 20 | 37 | 40 | 24 | 43 |
| | 25 | 33 | 9 | 22 | 36 | 30 | 35 | 11 | 10 | 17 | 32 | 13 | 12 | 41 | 15 | 14 | 19 | 16 | 8 | 44 | 29 | 28 | |
| 6/15 | 17 | 13 | 25 | 24 | 14 | 21 | 1 | 37 | 2 | 3 | 11 | 22 | 18 | 5 | 10 | 23 | 12 | 4 | 26 | 16 | 38 | 36 | 33 |
| | 39 | 0 | 6 | 7 | 31 | 32 | 34 | 27 | 35 | 15 | 9 | 30 | 28 | 19 | 8 | 20 | 29 | 40 | 41 | 42 | 43 | 44 | |
| 7/15 | 13 | 16 | 4 | 12 | 44 | 15 | 8 | 14 | 0 | 3 | 30 | 20 | 35 | 21 | 10 | 6 | 19 | 17 | 26 | 39 | 7 | 24 | 9 |
| | 27 | 5 | 37 | 23 | 32 | 40 | 31 | 38 | 42 | 34 | 25 | 36 | 2 | 22 | 43 | 33 | 28 | 1 | 18 | 11 | 41 | 29 | |
| 8/15 | 41 | 2 | 12 | 6 | 33 | 1 | 13 | 11 | 26 | 10 | 39 | 43 | 36 | 23 | 42 | 7 | 44 | 20 | 8 | 38 | 18 | 22 | 24 |
| | 40 | 4 | 28 | 29 | 19 | 14 | 5 | 9 | 0 | 30 | 25 | 35 | 37 | 27 | 32 | 31 | 34 | 21 | 3 | 15 | 17 | 16 | |
| 9/15 | 5 | 7 | 9 | 22 | 10 | 12 | 3 | 43 | 6 | 4 | 24 | 13 | 14 | 11 | 15 | 18 | 19 | 17 | 16 | 41 | 25 | 26 | 20 |
| | 23 | 21 | 33 | 31 | 28 | 39 | 36 | 30 | 37 | 27 | 32 | 34 | 35 | 29 | 2 | 42 | 0 | 1 | 8 | 40 | 38 | 44 | |
| 10/15 | 28 | 20 | 18 | 38 | 39 | 2 | 3 | 30 | 19 | 4 | 14 | 36 | 7 | 0 | 25 | 17 | 10 | 6 | 33 | 15 | 8 | 26 | 42 |
| | 24 | 11 | 21 | 23 | 5 | 40 | 41 | 29 | 32 | 37 | 44 | 43 | 31 | 35 | 34 | 22 | 1 | 16 | 27 | 9 | 13 | 12 | |
| 11/15 | 8 | 13 | 0 | 11 | 9 | 4 | 36 | 37 | 16 | 3 | 10 | 14 | 24 | 20 | 33 | 34 | 25 | 2 | 21 | 31 | 12 | 19 | 7 |
| | 5 | 27 | 23 | 26 | 1 | 18 | 22 | 35 | 6 | 32 | 30 | 28 | 15 | 29 | 17 | 39 | 38 | 40 | 41 | 42 | 43 | 44 | |
| 12/15 | 28 | 21 | 10 | 15 | 8 | 22 | 26 | 2 | 14 | 1 | 27 | 3 | 39 | 20 | 34 | 25 | 12 | 6 | 7 | 40 | 30 | 29 | 38 |
| | 16 | 43 | 33 | 4 | 35 | 9 | 32 | 5 | 36 | 0 | 41 | 37 | 18 | 17 | 13 | 24 | 42 | 31 | 23 | 19 | 11 | 44 | |
| 13/15 | 9 | 13 | 10 | 7 | 11 | 6 | 1 | 14 | 12 | 8 | 21 | 15 | 4 | 36 | 25 | 30 | 24 | 28 | 29 | 20 | 27 | 5 | 18 |
| | 17 | 22 | 33 | 0 | 16 | 23 | 31 | 42 | 3 | 40 | 39 | 41 | 43 | 37 | 44 | 26 | 2 | 19 | 38 | 32 | 35 | 34 | |

# *Annex C*: Constellation Definitions and Figures

## C.1 CONSTELLATION DEFINITIONS

This Annex contains the definitions of the constellations used. Table C.1.1 describes the mapping for QPSK. Table C.1.2 to Table C.1.7 define the position vectors for the NUCs from 16QAM up to 256QAM. Table C.1.8 to Table C.1.11 summarize the position vectors for the NUCs for 1024QAM and 4096QAM.

**Table C.1.1** QPSK Definition Table for All Code Rates

| Input Data Cell *y* | Constellation Point $z_s$ |
|---|---|
| 00 | (1 + j1)/√2 |
| 01 | (-1 + j1) /√2 |
| 10 | (+1 - j1) /√2 |
| 11 | (-1 - j1) /√2 |

**Table C.1.2** 16QAM Definition Table for Code Rates 2/15-7/15

| w/CR | 2/15 | 3/15 | 4/15 | 5/15 | 6/15 | 7/15 |
|---|---|---|---|---|---|---|
| w0 | 0.7062+j0.7075 | 0.3620+j0.5534 | 0.3412+j0.5241 | 0.3192+j0.5011 | 0.5115+j1.2092 | 0.2592+j0.4888 |
| w1 | 0.7075+j0.7062 | 0.5534+j0.3620 | 0.5241+j0.3412 | 0.5011+j0.3192 | 1.2092+j0.5115 | 0.4888+j0.2592 |
| w2 | 0.7072+j0.7077 | 0.5940+j1.1000 | 0.5797+j1.1282 | 0.5575+j1.1559 | 0.2663+j0.4530 | 0.5072+j1.1980 |
| w3 | 0.7077+j0.7072 | 1.1000+j0.5940 | 1.1282+j0.5797 | 1.1559+j0.5575 | 0.4530+j0.2663 | 1.1980+j0.5072 |

**Table C.1.3** 16QAM Definition Table for Code Rates 8/15-13/15

| w/CR | 8/15 | 9/15 | 10/15 | 11/15 | 12/15 | 13/15 |
|---|---|---|---|---|---|---|
| w0 | 0.2535+j0.4923 | 0.2386+j0.5296 | 0.4487+j1.1657 | 0.9342+j0.9847 | 0.9555+j0.9555 | 0.9517+j0.9511 |
| w1 | 0.4923+j0.2535 | 0.5296+j0.2386 | 1.2080+j0.5377 | 0.9866+j0.2903 | 0.9555+j0.2949 | 0.9524+j0.3061 |
| w2 | 0.4927+j1.2044 | 0.4882+j1.1934 | 0.2213+j0.4416 | 0.2716+j0.9325 | 0.2949+j0.9555 | 0.3067+j0.9524 |
| w3 | 1.2044+j0.4927 | 1.1934+j0.4882 | 0.6186+j0.2544 | 0.2901+j0.2695 | 0.2949+j0.2949 | 0.3061+j0.3067 |

**Table C.1.4** 64QAM Definition Table for Code Rates 2/15-7/15

| w/CR | 2/15 | 3/15 | 4/15 | 5/15 | 6/15 | 7/15 |
|---|---|---|---|---|---|---|
| w0 | 0.6474+j0.9831 | 0.5472+j1.1591 | 0.5008+j1.2136 | 1.4327+j0.3305 | 1.4521+j0.3005 | 0.1567+j0.3112 |
| w1 | 0.6438+j0.9829 | 0.5473+j1.1573 | 0.4994+j1.2194 | 1.0909+j0.2971 | 1.2657+j0.8178 | 0.1709+j0.3037 |
| w2 | 0.6471+j0.9767 | 0.5467+j1.1599 | 0.5313+j1.1715 | 1.2484+j0.7803 | 1.0666+j0.2744 | 0.2093+j0.6562 |
| w3 | 0.6444+j0.9762 | 0.5479+j1.1585 | 0.5299+j1.1788 | 0.9762+j0.5715 | 0.9500+j0.5641 | 0.3315+j0.6038 |
| w4 | 0.9839+j0.6475 | 1.1578+j0.5478 | 1.2107+j0.5037 | 0.3309+j1.4326 | 0.3011+j1.4529 | 0.3112+j0.1567 |
| w5 | 0.9778+j0.6474 | 1.1576+j0.5475 | 1.2209+j0.5008 | 0.2979+j1.0923 | 0.8202+j1.2651 | 0.3037+j0.1709 |
| w6 | 0.9835+j0.6434 | 1.1591+j0.5475 | 1.1715+j0.5299 | 0.7829+j1.2477 | 0.2750+j1.0676 | 0.6562+j0.2093 |
| w7 | 0.9777+j0.6433 | 1.1591+j0.5475 | 1.1802+j0.5270 | 0.5739+j0.9763 | 0.5656+j0.9499 | 0.6038+j0.3315 |
| w8 | 0.4659+j0.6393 | 0.3163+j0.5072 | 0.2744+j0.4762 | 0.3901+j0.2112 | 0.3553+j0.1948 | 0.2959+j1.4877 |
| w9 | 0.4643+j0.6386 | 0.3163+j0.5072 | 0.2729+j0.4762 | 0.5317+j0.2475 | 0.3569+j0.2094 | 0.8427+j1.2612 |
| w10 | 0.4661+j0.6353 | 0.3163+j0.5072 | 0.2773+j0.4791 | 0.3945+j0.2289 | 0.5596+j0.2431 | 0.2389+j1.0228 |
| w11 | 0.4639+j0.6350 | 0.3163+j0.5072 | 0.2773+j0.4791 | 0.5236+j0.2894 | 0.5410+j0.3002 | 0.5559+j0.8912 |
| w12 | 0.6378+j0.4671 | 0.5087+j0.3163 | 0.4762+j0.2729 | 0.2108+j0.3911 | 0.1946+j0.3566 | 1.4877+j0.2959 |
| w13 | 0.6352+j0.4673 | 0.5087+j0.3163 | 0.4762+j0.2729 | 0.2475+j0.5327 | 0.2094+j0.3579 | 1.2612+j0.8427 |
| w14 | 0.6385+j0.4656 | 0.5087+j0.3163 | 0.4791+j0.2773 | 0.2287+j0.3955 | 0.2430+j0.5607 | 1.0228+j0.2389 |
| w15 | 0.6353+j0.4653 | 0.5087+j0.3163 | 0.4791+j0.2758 | 0.2898+j0.5246 | 0.3004+j0.5417 | 0.8912+j0.5559 |

**Table C.1.5** 64QAM Definition Table for Code Rates 8/15-13/15

| w/CR | 8/15 | 9/15 | 10/15 | 11/15 | 12/15 | 13/15 |
|---|---|---|---|---|---|---|
| w0 | 1.4827+j0.2920 | 0.1305+j0.3311 | 0.1177+j0.1729 | 1.4443+j0.2683 | 1.4480+j0.2403 | 1.4319+j0.2300 |
| w1 | 1.2563+j0.8411 | 0.1633+j0.3162 | 0.1601+j0.3212 | 0.7471+j1.2243 | 0.6406+j1.1995 | 1.0762+j0.9250 |
| w2 | 1.0211+j0.2174 | 0.1622+j0.7113 | 0.1352+j0.7279 | 1.1749+j0.7734 | 1.0952+j0.9115 | 0.6290+j1.1820 |
| w3 | 0.8798+j0.5702 | 0.3905+j0.6163 | 0.3246+j0.6148 | 0.7138+j0.8201 | 0.6868+j0.8108 | 0.6851+j0.8072 |
| w4 | 0.2920+j1.4827 | 0.3311+j0.1305 | 0.4192+j0.1179 | 0.1638+j1.0769 | 1.0500+j0.1642 | 1.0443+j0.1688 |
| w5 | 0.8410+j1.2563 | 0.3162+j0.1633 | 0.4033+j0.2421 | 0.2927+j1.4217 | 0.7170+j0.1473 | 1.0635+j0.5305 |
| w6 | 0.2174+j1.0211 | 0.7113+j0.1622 | 0.7524+j0.1581 | 0.1462+j0.7457 | 1.0519+j0.5188 | 0.7220+j0.1540 |
| w7 | 0.5702+j0.8798 | 0.6163+j0.3905 | 0.5996+j0.4330 | 0.4134+j0.7408 | 0.7146+j0.4532 | 0.7151+j0.4711 |
| w8 | 0.3040+j0.1475 | 0.2909+j1.4626 | 0.2902+j1.4611 | 1.0203+j0.1517 | 0.1677+j1.0405 | 0.2099+j1.4205 |
| w9 | 0.3028+j0.1691 | 0.8285+j1.2399 | 0.8180+j1.2291 | 0.6653+j0.1357 | 0.2402+j1.4087 | 0.1190+j0.6677 |
| w10 | 0.6855+j0.1871 | 0.2062+j1.0367 | 0.2036+j1.0575 | 0.9639+j0.4465 | 0.1369+j0.7073 | 0.2031+j1.0551 |
| w11 | 0.6126+j0.3563 | 0.5872+j0.8789 | 0.5641+j0.8965 | 0.6746+j0.4339 | 0.4044+j0.7057 | 0.3722+j0.7548 |
| w12 | 0.1475+j0.3040 | 1.4626+j0.2909 | 1.4453+j0.2907 | 0.1271+j0.1428 | 0.1374+j0.1295 | 0.1438+j0.1287 |
| w13 | 0.1691+j0.3028 | 1.2399+j0.8285 | 1.2157+j0.8186 | 0.3782+j0.1406 | 0.4185+j0.1357 | 0.1432+j0.3903 |
| w14 | 0.1871+j0.6855 | 1.0367+j0.2062 | 1.0447+j0.2242 | 0.1311+j0.4288 | 0.1325+j0.3998 | 0.4298+j0.1384 |
| w15 | 0.3563+j0.6126 | 0.8789+j0.5872 | 0.8497+j0.6176 | 0.3919+j0.4276 | 0.4122+j0.4120 | 0.4215+j0.4279 |

**Table C.1.6** 256QAM Definition Table for Code Rates 2/15-7/15

| w/Shape | NUC_256_2/15 | NUC_256_3/15 | NUC_256_4/15 | NUC_256_5/15 | NUC_256_6/15 | NUC_256_7/15 |
|---|---|---|---|---|---|---|
| w0 | 0.5553+j1.1262 | 0.5229+j1.1810 | 0.2975+j1.0564 | 0.1524+j0.3087 | 0.1430+j0.3078 | 0.1170+j0.3003 |
| w1 | 0.5673+j1.1336 | 0.5384+j1.1625 | 0.5862+j0.9617 | 0.1525+j0.3087 | 0.1430+j0.3077 | 0.1171+j0.3003 |
| w2 | 0.5593+j1.1204 | 0.5148+j1.1943 | 0.2909+j1.0696 | 0.1513+j0.3043 | 0.1413+j0.3003 | 0.1204+j0.3233 |
| w3 | 0.5636+j1.1321 | 0.5288+j1.1751 | 0.5796+j0.9689 | 0.1513+j0.3043 | 0.1414+j0.3002 | 0.1204+j0.3233 |
| w4 | 0.5525+j1.1249 | 0.4985+j1.2202 | 0.2953+j1.3357 | 0.1682+j0.3004 | 0.1637+j0.2973 | 0.1454+j0.2877 |
| w5 | 0.5637+j1.1320 | 0.5111+j1.1973 | 0.7488+j1.2365 | 0.1682+j0.3005 | 0.1636+j0.2973 | 0.1453+j0.2877 |
| w6 | 0.5598+j1.1181 | 0.4889+j1.2357 | 0.3004+j1.5114 | 0.1663+j0.2964 | 0.1604+j0.2905 | 0.1566+j0.3074 |
| w7 | 0.5659+j1.1274 | 0.5045+j1.2113 | 0.8151+j1.3816 | 0.1663+j0.2964 | 0.1603+j0.2905 | 0.1565+j0.3074 |
| w8 | 0.5579+j1.1381 | 0.5222+j1.1817 | 0.3004+j1.0535 | 0.1964+j0.6584 | 0.1768+j0.6686 | 0.1427+j0.6856 |
| w9 | 0.5617+j1.1471 | 0.5370+j1.1640 | 0.5847+j0.9631 | 0.1965+j0.6583 | 0.1793+j0.6679 | 0.1562+j0.6826 |
| w10 | 0.5593+j1.1346 | 0.5133+j1.1950 | 0.2931+j1.0659 | 0.1967+j0.6652 | 0.1769+j0.6707 | 0.1422+j0.6584 |
| w11 | 0.5672+j1.1430 | 0.5303+j1.1751 | 0.5825+j0.9668 | 0.1968+j0.6652 | 0.1793+j0.6700 | 0.1529+j0.6560 |
| w12 | 0.5533+j1.1355 | 0.4971+j1.2216 | 0.2953+j1.3189 | 0.3371+j0.5987 | 0.3506+j0.5961 | 0.3840+j0.5856 |
| w13 | 0.5632+j1.1421 | 0.5126+j1.1995 | 0.7466+j1.2168 | 0.3370+j0.5987 | 0.3484+j0.5974 | 0.3723+j0.5931 |
| w14 | 0.5567+j1.1325 | 0.4882+j1.2371 | 0.2960+j1.4654 | 0.3414+j0.6039 | 0.3523+j0.5975 | 0.3651+j0.5660 |
| w15 | 0.5641+j1.1363 | 0.5045+j1.2128 | 0.8297+j1.3539 | 0.3413+j0.6039 | 0.3501+j0.5987 | 0.3559+j0.5718 |
| w16 | 1.1309+j0.5597 | 1.1795+j0.5251 | 1.0637+j0.2960 | 0.3087+j0.1524 | 0.3078+j0.1430 | 0.3003+j0.1170 |
| w17 | 1.1405+j0.5660 | 1.1625+j0.5384 | 0.9617+j0.5811 | 0.3087+j0.1525 | 0.3077+j0.1430 | 0.3003+j0.1171 |
| w18 | 1.1348+j0.5588 | 1.1914+j0.5133 | 1.0732+j0.2931 | 0.3043+j0.1513 | 0.3003+j0.1413 | 0.3233+j0.1204 |
| w19 | 1.1491+j0.5638 | 1.1744+j0.5296 | 0.9682+j0.5818 | 0.3043+j0.1513 | 0.3002+j0.1414 | 0.3233+j0.1204 |
| w20 | 1.1245+j0.5615 | 1.2209+j0.4993 | 1.3619+j0.2997 | 0.3004+j0.1682 | 0.2973+j0.1637 | 0.2877+j0.1454 |
| w21 | 1.1333+j0.5627 | 1.2002+j0.5148 | 1.2249+j0.7546 | 0.3005+j0.1682 | 0.2973+j0.1636 | 0.2877+j0.1453 |
| w22 | 1.1284+j0.5578 | 1.2342+j0.4882 | 1.5427+j0.3106 | 0.2964+j0.1663 | 0.2905+j0.1604 | 0.3074+j0.1566 |
| w23 | 1.1436+j0.5636 | 1.2142+j0.5052 | 1.3969+j0.8523 | 0.2964+j0.1663 | 0.2905+j0.1603 | 0.3074+j0.1565 |
| w24 | 1.1196+j0.5620 | 1.1803+j0.5229 | 1.0615+j0.2945 | 0.6584+j0.1964 | 0.6686+j0.1768 | 0.6856+j0.1427 |
| w25 | 1.1347+j0.5665 | 1.1640+j0.5399 | 0.9631+j0.5818 | 0.6583+j0.1965 | 0.6679+j0.1793 | 0.6826+j0.1562 |
| w26 | 1.1379+j0.5611 | 1.1921+j0.5133 | 1.0710+j0.2924 | 0.6652+j0.1967 | 0.6707+j0.1769 | 0.6584+j0.1422 |
| w27 | 1.1440+j0.5638 | 1.1758+j0.5303 | 0.9675+j0.5825 | 0.6652+j0.1968 | 0.6700+j0.1793 | 0.6560+j0.1529 |
| w28 | 1.1221+j0.5594 | 1.2209+j0.4971 | 1.3255+j0.2975 | 0.5987+j0.3371 | 0.5961+j0.3506 | 0.5856+j0.3840 |
| w29 | 1.1318+j0.5686 | 1.2024+j0.5148 | 1.1979+j0.7495 | 0.5987+j0.3370 | 0.5974+j0.3484 | 0.5931+j0.3723 |
| w30 | 1.1302+j0.5619 | 1.2349+j0.4889 | 1.4560+j0.3040 | 0.6039+j0.3414 | 0.5975+j0.3523 | 0.5660+j0.3651 |
| w31 | 1.1386+j0.5662 | 1.2150+j0.5045 | 1.3269+j0.8414 | 0.6039+j0.3413 | 0.5987+j0.3501 | 0.5718+j0.3559 |
| w32 | 0.3394+j0.5381 | 0.2740+j0.4771 | 0.2493+j0.5585 | 0.3183+j1.5992 | 0.2071+j1.6690 | 0.1683+j1.7041 |
| w33 | 0.3397+j0.5360 | 0.2762+j0.4801 | 0.2960+j0.5344 | 0.3186+j1.5991 | 0.4482+j1.6210 | 0.4972+j1.6386 |
| w34 | 0.3387+j0.5324 | 0.2733+j0.4757 | 0.2450+j0.5417 | 0.2756+j1.3848 | 0.2080+j1.3641 | 0.1495+j1.3560 |
| w35 | 0.3400+j0.5335 | 0.2748+j0.4779 | 0.2873+j0.5191 | 0.2759+j1.3847 | 0.3307+j1.3397 | 0.3814+j1.3099 |
| w36 | 0.3374+j0.5306 | 0.2703+j0.4742 | 0.2049+j0.3922 | 0.9060+j1.3557 | 1.0341+j1.3264 | 1.0862+j1.3238 |
| w37 | 0.3405+j0.5343 | 0.2725+j0.4764 | 0.2173+j0.3806 | 0.9058+j1.3559 | 0.8297+j1.4630 | 0.8074+j1.5101 |
| w38 | 0.3379+j0.5324 | 0.2696+j0.4727 | 0.1990+j0.3755 | 0.7846+j1.1739 | 0.8178+j1.1114 | 0.8534+j1.0644 |
| w39 | 0.3400+j0.5317 | 0.2718+j0.4749 | 0.2107+j0.3645 | 0.7843+j1.1741 | 0.7138+j1.1809 | 0.6568+j1.1958 |
| w40 | 0.3397+j0.5370 | 0.2740+j0.4779 | 0.2493+j0.5599 | 0.2257+j0.9956 | 0.1957+j0.9674 | 0.1552+j0.9481 |
| w41 | 0.3400+j0.5383 | 0.2755+j0.4793 | 0.2975+j0.5351 | 0.2259+j0.9956 | 0.2170+j0.9629 | 0.2200+j0.9352 |
| w42 | 0.3381+j0.5347 | 0.2725+j0.4757 | 0.2450+j0.5439 | 0.2276+j1.0326 | 0.1977+j1.0341 | 0.1577+j1.0449 |
| w43 | 0.3382+j0.5347 | 0.2748+j0.4779 | 0.2887+j0.5213 | 0.2278+j1.0326 | 0.2288+j1.0277 | 0.2548+j1.0255 |
| w44 | 0.3379+j0.5342 | 0.2711+j0.4734 | 0.2056+j0.3937 | 0.5446+j0.8635 | 0.5458+j0.8224 | 0.5609+j0.7800 |

| | | | | | | |
|---|---|---|---|---|---|---|
| w45 | 0.3389+j0.5332 | 0.2725+j0.4764 | 0.2187+j0.3820 | 0.5445+j0.8636 | 0.5276+j0.8342 | 0.5060+j0.8167 |
| w46 | 0.3402+j0.5347 | 0.2696+j0.4720 | 0.1998+j0.3762 | 0.5694+j0.8910 | 0.5916+j0.8709 | 0.6276+j0.8501 |
| w47 | 0.3384+j0.5340 | 0.2711+j0.4742 | 0.2122+j0.3667 | 0.5692+j0.8911 | 0.5651+j0.8883 | 0.5452+j0.9052 |
| w48 | 0.5350+j0.3394 | 0.4771+j0.2740 | 0.5607+j0.2486 | 1.5992+j0.3183 | 1.6690+j0.2071 | 1.7041+j0.1683 |
| w49 | 0.5363+j0.3397 | 0.4786+j0.2762 | 0.5381+j0.2960 | 1.5991+j0.3186 | 1.6210+j0.4482 | 1.6386+j0.4972 |
| w50 | 0.5342+j0.3389 | 0.4764+j0.2725 | 0.5439+j0.2442 | 1.3848+j0.2756 | 1.3641+j0.2080 | 1.3560+j0.1495 |
| w51 | 0.5384+j0.3380 | 0.4771+j0.2748 | 0.5220+j0.2865 | 1.3847+j0.2759 | 1.3397+j0.3307 | 1.3099+j0.3814 |
| w52 | 0.5329+j0.3363 | 0.4734+j0.2703 | 0.3908+j0.2049 | 1.3557+j0.9060 | 1.3264+j1.0341 | 1.3238+j1.0862 |
| w53 | 0.5330+j0.3387 | 0.4757+j0.2725 | 0.3813+j0.2173 | 1.3559+j0.9058 | 1.4630+j0.8297 | 1.5101+j0.8074 |
| w54 | 0.5311+j0.3389 | 0.4734+j0.2696 | 0.3740+j0.1998 | 1.1739+j0.7846 | 1.1114+j0.8178 | 1.0644+j0.8534 |
| w55 | 0.5332+j0.3380 | 0.4742+j0.2711 | 0.3653+j0.2100 | 1.1741+j0.7843 | 1.1809+j0.7138 | 1.1958+j0.6568 |
| w56 | 0.5313+j0.3397 | 0.4771+j0.2740 | 0.5643+j0.2486 | 0.9956+j0.2257 | 0.9674+j0.1957 | 0.9481+j0.1552 |
| w57 | 0.5324+j0.3400 | 0.4779+j0.2762 | 0.5410+j0.2967 | 0.9956+j0.2259 | 0.9629+j0.2170 | 0.9352+j0.2200 |
| w58 | 0.5339+j0.3402 | 0.4764+j0.2725 | 0.5475+j0.2435 | 1.0326+j0.2276 | 1.0341+j0.1977 | 1.0449+j0.1577 |
| w59 | 0.5360+j0.3405 | 0.4771+j0.2748 | 0.5257+j0.2880 | 1.0326+j0.2278 | 1.0277+j0.2288 | 1.0255+j0.2548 |
| w60 | 0.5285+j0.3397 | 0.4742+j0.2703 | 0.3937+j0.2049 | 0.8635+j0.5446 | 0.8224+j0.5458 | 0.7800+j0.5609 |
| w61 | 0.5317+j0.3379 | 0.4749+j0.2725 | 0.3850+j0.2187 | 0.8636+j0.5445 | 0.8342+j0.5276 | 0.8167+j0.5060 |
| w62 | 0.5319+j0.3381 | 0.4734+j0.2696 | 0.3762+j0.1998 | 0.8910+j0.5694 | 0.8709+j0.5916 | 0.8501+j0.6276 |
| w63 | 0.5327+j0.3395 | 0.4749+j0.2711 | 0.3689+j0.2114 | 0.8911+j0.5692 | 0.8883+j0.5651 | 0.9052+j0.5452 |

**Table C.1.7** 256QAM Definition Table for Code Rates 8/15-13/15

| w/Shape | NUC_256_8/15 | NUC_256_9/15 | NUC_256_10/15 | NUC_256_11/15 | NUC_256_12/15 | NUC_256_13/15 |
|---|---|---|---|---|---|---|
| w0 | 0.0995+j0.2435 | 0.0899+j0.1337 | 0.0754+j0.2310 | 0.0593+j0.2193 | 1.1980+j1.1541 | 1.2412+j1.0688 |
| w1 | 0.0996+j0.2434 | 0.0910+j0.1377 | 0.0768+j0.2305 | 0.0690+j0.3047 | 0.9192+j1.2082 | 1.2668+j0.8034 |
| w2 | 0.1169+j0.3886 | 0.0873+j0.3862 | 0.0924+j0.4136 | 0.0663+j0.4879 | 1.2778+j0.8523 | 0.9860+j1.1758 |
| w3 | 0.1179+j0.3883 | 0.0883+j0.3873 | 0.1043+j0.4125 | 0.1151+j0.4474 | 1.0390+j0.9253 | 1.0365+j0.9065 |
| w4 | 0.1192+j0.2345 | 0.1115+j0.1442 | 0.0829+j0.1135 | 0.1689+j0.2163 | 0.6057+j1.2200 | 1.2111+j0.5135 |
| w5 | 0.1192+j0.2345 | 0.1135+j0.1472 | 0.0836+j0.1149 | 0.1971+j0.2525 | 0.7371+j1.4217 | 1.4187+j0.6066 |
| w6 | 0.1953+j0.3558 | 0.2067+j0.3591 | 0.2682+j0.3856 | 0.3096+j0.3796 | 0.6678+j1.0021 | 1.0103+j0.4879 |
| w7 | 0.1944+j0.3563 | 0.1975+j0.3621 | 0.2531+j0.3906 | 0.2489+j0.3933 | 0.8412+j0.9448 | 1.0380+j0.6906 |
| w8 | 0.1293+j0.7217 | 0.1048+j0.7533 | 0.0836+j0.7817 | 0.0790+j0.7970 | 1.2128+j0.5373 | 0.6963+j1.3442 |
| w9 | 0.1616+j0.7151 | 0.1770+j0.7412 | 0.2052+j0.7608 | 0.2340+j0.7710 | 1.0048+j0.5165 | 0.7089+j1.1122 |
| w10 | 0.1287+j0.6355 | 0.1022+j0.5904 | 0.0838+j0.6034 | 0.0723+j0.6395 | 1.4321+j0.6343 | 0.1256+j1.4745 |
| w11 | 0.1456+j0.6318 | 0.1191+j0.5890 | 0.1394+j0.5961 | 0.1896+j0.6163 | 1.0245+j0.7152 | 0.8331+j0.9455 |
| w12 | 0.4191+j0.6016 | 0.4264+j0.6230 | 0.4861+j0.6331 | 0.5090+j0.6272 | 0.6384+j0.6073 | 0.6615+j0.6012 |
| w13 | 0.3916+j0.6198 | 0.3650+j0.6689 | 0.3661+j0.7034 | 0.3787+j0.7126 | 0.8175+j0.5684 | 0.6894+j0.7594 |
| w14 | 0.3585+j0.5403 | 0.3254+j0.5153 | 0.3732+j0.5159 | 0.4079+j0.5049 | 0.6568+j0.7801 | 0.8373+j0.5633 |
| w15 | 0.3439+j0.5497 | 0.2959+j0.5302 | 0.3095+j0.5511 | 0.3088+j0.5677 | 0.8311+j0.7459 | 0.8552+j0.7410 |
| w16 | 0.2435+j0.0995 | 0.3256+j0.0768 | 0.3030+j0.0811 | 0.0675+j0.0626 | 0.1349+j1.4742 | 1.2666+j0.1027 |
| w17 | 0.2434+j0.0996 | 0.3266+j0.0870 | 0.3017+j0.0853 | 0.3475+j0.0595 | 0.1105+j1.2309 | 1.4915+j0.1198 |
| w18 | 0.3886+j0.1169 | 0.4721+j0.0994 | 0.4758+j0.0932 | 0.5482+j0.0626 | 0.0634+j0.9796 | 1.0766+j0.0945 |
| w19 | 0.3883+j0.1179 | 0.4721+j0.1206 | 0.4676+j0.1242 | 0.4784+j0.1124 | 0.1891+j1.0198 | 0.9007+j0.0848 |
| w20 | 0.2345+j0.1192 | 0.2927+j0.1267 | 0.2425+j0.1081 | 0.1674+j0.0751 | 0.4142+j1.4461 | 1.2454+j0.3064 |
| w21 | 0.2345+j0.1192 | 0.2947+j0.1296 | 0.2447+j0.1115 | 0.2856+j0.1132 | 0.3323+j1.2279 | 1.4646+j0.3600 |
| w22 | 0.3558+j0.1953 | 0.3823+j0.2592 | 0.3837+j0.2813 | 0.4134+j0.3028 | 0.4998+j0.9827 | 1.0570+j0.2995 |
| w23 | 0.3563+j0.1944 | 0.3944+j0.2521 | 0.3959+j0.2642 | 0.4235+j0.2289 | 0.3467+j1.0202 | 0.9140+j0.2530 |
| w24 | 0.7217+j0.1293 | 0.7755+j0.1118 | 0.7929+j0.0859 | 0.8258+j0.0840 | 0.0680+j0.6501 | 0.5461+j0.0679 |

| | | | | | | |
|---|---|---|---|---|---|---|
| w25 | 0.7151+j0.1616 | 0.7513+j0.2154 | 0.7652+j0.2324 | 0.7936+j0.2483 | 0.2016+j0.6464 | 0.5681+j0.1947 |
| w26 | 0.6355+j0.1287 | 0.6591+j0.1033 | 0.6365+j0.0872 | 0.6788+j0.0783 | 0.0719+j0.8075 | 0.6874+j0.0537 |
| w27 | 0.6318+j0.1456 | 0.6446+j0.1737 | 0.6207+j0.1757 | 0.6501+j0.2025 | 0.2088+j0.8146 | 0.7375+j0.1492 |
| w28 | 0.6016+j0.4191 | 0.5906+j0.4930 | 0.6149+j0.5145 | 0.6246+j0.5211 | 0.4809+j0.6296 | 0.6290+j0.4553 |
| w29 | 0.6198+j0.3916 | 0.6538+j0.4155 | 0.6987+j0.3934 | 0.7241+j0.3961 | 0.3374+j0.6412 | 0.6007+j0.3177 |
| w30 | 0.5403+j0.3585 | 0.4981+j0.3921 | 0.5063+j0.4029 | 0.5144+j0.4089 | 0.4955+j0.8008 | 0.7885+j0.4231 |
| w31 | 0.5497+j0.3439 | 0.5373+j0.3586 | 0.5526+j0.3356 | 0.5918+j0.3146 | 0.3431+j0.8141 | 0.7627+j0.2849 |
| w32 | 0.1665+j1.6859 | 0.1630+j1.6621 | 0.1598+j1.6262 | 0.1631+j1.5801 | 1.2731+j0.1108 | 0.0816+j1.1632 |
| w33 | 0.4919+j1.6211 | 0.4720+j1.5898 | 0.4733+j1.5637 | 0.4806+j1.5133 | 1.0794+j0.0977 | 0.0830+j0.9813 |
| w34 | 0.1360+j1.3498 | 0.1268+j1.3488 | 0.1307+j1.3502 | 0.1260+j1.3365 | 1.5126+j0.1256 | 0.2528+j1.2315 |
| w35 | 0.3914+j1.2989 | 0.3752+j1.2961 | 0.3877+j1.2983 | 0.3750+j1.2897 | 0.9029+j0.0853 | 0.2502+j1.0100 |
| w36 | 1.0746+j1.3096 | 1.0398+j1.2991 | 1.0328+j1.2617 | 1.0324+j1.2029 | 0.5429+j0.0694 | 0.0732+j0.6827 |
| w37 | 0.7987+j1.4940 | 0.7733+j1.4772 | 0.7675+j1.4398 | 0.7737+j1.3837 | 0.6795+j0.0559 | 0.0811+j0.8293 |
| w38 | 0.8585+j1.0504 | 0.8380+j1.0552 | 0.8496+j1.0508 | 0.8350+j1.0529 | 0.5628+j0.1945 | 0.2159+j0.6673 |
| w39 | 0.6419+j1.1951 | 0.6242+j1.2081 | 0.6297+j1.1967 | 0.6147+j1.1949 | 0.7326+j0.1410 | 0.2359+j0.8283 |
| w40 | 0.1334+j0.9483 | 0.1103+j0.9397 | 0.0910+j0.9531 | 0.0929+j0.9596 | 1.2283+j0.3217 | 0.4302+j1.4458 |
| w41 | 0.2402+j0.9271 | 0.2415+j0.9155 | 0.2649+j0.9198 | 0.2768+j0.9260 | 1.0269+j0.3261 | 0.5852+j0.9680 |
| w42 | 0.1323+j1.0786 | 0.1118+j1.1163 | 0.1080+j1.1340 | 0.1095+j1.1349 | 1.4663+j0.3716 | 0.4528+j1.2074 |
| w43 | 0.2910+j1.0470 | 0.3079+j1.0866 | 0.3214+j1.0926 | 0.3250+j1.0941 | 0.9085+j0.2470 | 0.4167+j1.0099 |
| w44 | 0.5764+j0.7648 | 0.5647+j0.7638 | 0.5941+j0.7527 | 0.6086+j0.7556 | 0.6160+j0.4549 | 0.5035+j0.6307 |
| w45 | 0.4860+j0.8252 | 0.4385+j0.8433 | 0.4371+j0.8528 | 0.4514+j0.8566 | 0.7818+j0.4247 | 0.5359+j0.7954 |
| w46 | 0.6693+j0.8561 | 0.6846+j0.8841 | 0.7093+j0.8880 | 0.7161+j0.8933 | 0.5938+j0.3170 | 0.3580+j0.6532 |
| w47 | 0.5348+j0.9459 | 0.5165+j1.0034 | 0.5235+j1.0090 | 0.5294+j1.0121 | 0.7600+j0.2850 | 0.3841+j0.8207 |
| w48 | 1.6859+j0.1665 | 1.6489+j0.1630 | 1.6180+j0.1602 | 1.5809+j0.1471 | 0.0595+j0.0707 | 0.0576+j0.0745 |
| w49 | 1.6211+j0.4919 | 1.5848+j0.4983 | 1.5540+j0.4734 | 1.5253+j0.4385 | 0.1722+j0.0706 | 0.0581+j0.2241 |
| w50 | 1.3498+j0.1360 | 1.3437+j0.1389 | 1.3411+j0.1336 | 1.3380+j0.1363 | 0.0599+j0.2119 | 0.1720+j0.0742 |
| w51 | 1.2989+j0.3914 | 1.2850+j0.4025 | 1.2883+j0.3955 | 1.2837+j0.4026 | 0.1748+j0.2114 | 0.1753+j0.2222 |
| w52 | 1.3096+j1.0746 | 1.2728+j1.0661 | 1.2561+j1.0337 | 1.2476+j0.9785 | 0.4134+j0.0701 | 0.0652+j0.5269 |
| w53 | 1.4940+j0.7987 | 1.4509+j0.7925 | 1.4311+j0.7676 | 1.4137+j0.7196 | 0.2935+j0.0705 | 0.0611+j0.3767 |
| w54 | 1.0504+j0.8585 | 1.0249+j0.8794 | 1.0362+j0.8626 | 1.0246+j0.8681 | 0.4231+j0.2066 | 0.1972+j0.5178 |
| w55 | 1.1951+j0.6419 | 1.1758+j0.6545 | 1.1845+j0.6419 | 1.1771+j0.6494 | 0.2979+j0.2100 | 0.1836+j0.3695 |
| w56 | 0.9483+j0.1334 | 0.9629+j0.1113 | 0.9546+j0.0957 | 0.9782+j0.0985 | 0.0638+j0.5002 | 0.4145+j0.0709 |
| w57 | 0.9271+j0.2402 | 0.9226+j0.2849 | 0.9163+j0.2834 | 0.9383+j0.2922 | 0.1905+j0.4966 | 0.4266+j0.2100 |
| w58 | 1.0786+j0.1323 | 1.1062+j0.1118 | 1.1282+j0.1128 | 1.1455+j0.1158 | 0.0612+j0.3552 | 0.2912+j0.0730 |
| w59 | 1.0470+j0.2910 | 1.0674+j0.3393 | 1.0838+j0.3340 | 1.0972+j0.3418 | 0.1810+j0.3533 | 0.2982+j0.2177 |
| w60 | 0.7648+j0.5764 | 0.7234+j0.6223 | 0.7329+j0.6204 | 0.7446+j0.6273 | 0.4630+j0.4764 | 0.4766+j0.4821 |
| w61 | 0.8252+j0.4860 | 0.8211+j0.4860 | 0.8428+j0.4615 | 0.8573+j0.4721 | 0.3231+j0.4895 | 0.4497+j0.3448 |
| w62 | 0.8561+j0.6693 | 0.8457+j0.7260 | 0.8680+j0.7295 | 0.8767+j0.7377 | 0.4416+j0.3397 | 0.3334+j0.5025 |
| w63 | 0.9459+j0.5348 | 0.9640+j0.5518 | 0.9959+j0.5426 | 1.0059+j0.5518 | 0.3083+j0.3490 | 0.3125+j0.3601 |

**Table C.1.8** 1024QAM Definition Table for Code Rates 2/15-7/15

| u/CR | 2/15 | 3/15 | 4/15 | 5/15 | 6/15 | 7/15 |
|---|---|---|---|---|---|---|
| u0 | 0.3317 | 0.2382 | 0.1924 | 0.1313 | 0.1275 | 0.0951 |
| u1 | 0.3321 | 0.2556 | 0.1940 | 0.1311 | 0.1276 | 0.0949 |
| u2 | 0.3322 | 0.2749 | 0.2070 | 0.1269 | 0.1294 | 0.1319 |
| u3 | 0.3321 | 0.2558 | 0.2050 | 0.1271 | 0.1295 | 0.1322 |
| u4 | 0.3327 | 0.2748 | 0.3056 | 0.3516 | 0.3424 | 0.3170 |
| u5 | 0.3328 | 0.2949 | 0.3096 | 0.3504 | 0.3431 | 0.3174 |
| u6 | 0.3322 | 0.2749 | 0.2890 | 0.3569 | 0.3675 | 0.3936 |
| u7 | 0.3322 | 0.2558 | 0.2854 | 0.3581 | 0.3666 | 0.3921 |
| u8 | 0.9369 | 0.9486 | 0.7167 | 0.6295 | 0.6097 | 0.5786 |
| u9 | 0.9418 | 0.8348 | 0.7362 | 0.6301 | 0.6072 | 0.5789 |
| u10 | 0.9514 | 0.7810 | 0.7500 | 0.6953 | 0.7113 | 0.7205 |
| u11 | 0.9471 | 0.8348 | 0.7326 | 0.6903 | 0.7196 | 0.7456 |
| u12 | 0.9448 | 0.9463 | 0.9667 | 0.9753 | 0.9418 | 0.9299 |
| u13 | 0.9492 | 0.8336 | 0.9665 | 1.0185 | 1.0048 | 1.0084 |
| u14 | 0.9394 | 0.9459 | 1.1332 | 1.2021 | 1.2286 | 1.2349 |
| u15 | 0.9349 | 1.4299 | 1.4761 | 1.4981 | 1.5031 | 1.5118 |

**Table C.1.9** 1024QAM Definition Table for Code Rates 8/15-13/15

| u/CR | 8/15 | 9/15 | 10/15 | 11/15 | 12/15 | 13/15 |
|---|---|---|---|---|---|---|
| u0 | 0.0773 | 0.0638 | 0.0592 | 0.0502 | 0.0354 | 0.0325 |
| u1 | 0.0773 | 0.0638 | 0.0594 | 0.0637 | 0.0921 | 0.0967 |
| u2 | 0.1614 | 0.1757 | 0.1780 | 0.1615 | 0.1602 | 0.1623 |
| u3 | 0.1614 | 0.1756 | 0.1790 | 0.1842 | 0.2185 | 0.2280 |
| u4 | 0.3086 | 0.3069 | 0.2996 | 0.2760 | 0.2910 | 0.2957 |
| u5 | 0.3085 | 0.3067 | 0.3041 | 0.3178 | 0.3530 | 0.3645 |
| u6 | 0.4159 | 0.4333 | 0.4241 | 0.4040 | 0.4264 | 0.4361 |
| u7 | 0.4163 | 0.4343 | 0.4404 | 0.4686 | 0.4947 | 0.5100 |
| u8 | 0.5810 | 0.5765 | 0.5561 | 0.5535 | 0.5763 | 0.5878 |
| u9 | 0.5872 | 0.5862 | 0.6008 | 0.6362 | 0.6531 | 0.6696 |
| u10 | 0.7213 | 0.7282 | 0.7141 | 0.7293 | 0.7417 | 0.7566 |
| u11 | 0.7604 | 0.7705 | 0.8043 | 0.8302 | 0.8324 | 0.8497 |
| u12 | 0.9212 | 0.9218 | 0.9261 | 0.9432 | 0.9386 | 0.9498 |
| u13 | 1.0349 | 1.0364 | 1.0639 | 1.0704 | 1.0529 | 1.0588 |
| u14 | 1.2281 | 1.2234 | 1.2285 | 1.2158 | 1.1917 | 1.1795 |
| u15 | 1.4800 | 1.4646 | 1.4309 | 1.3884 | 1.3675 | 1.3184 |

**Table C.1.10** 4096QAM Definition Table for Code Rates 2/15-7/15

| u/CR | 2/15 | 3/15 | 4/15 | 5/15 | 6/15 | 7/15 |
|---|---|---|---|---|---|---|
| u0 | 0.2826 | 0.2038 | 0.1508 | 0.1257 | 0.1041 | 0.0810 |
| u1 | 0.2885 | 0.2038 | 0.1468 | 0.1257 | 0.1041 | 0.0808 |
| u2 | 0.2944 | 0.2155 | 0.1456 | 0.1257 | 0.1087 | 0.0807 |
| u3 | 0.2885 | 0.2155 | 0.1479 | 0.1257 | 0.1089 | 0.0810 |
| u4 | 0.2944 | 0.2155 | 0.1491 | 0.1257 | 0.1094 | 0.1456 |
| u5 | 0.3003 | 0.2155 | 0.1444 | 0.1257 | 0.1094 | 0.1457 |
| u6 | 0.2944 | 0.2097 | 0.1491 | 0.1257 | 0.1094 | 0.1456 |
| u7 | 0.2885 | 0.2038 | 0.1508 | 0.1257 | 0.1109 | 0.1456 |
| u8 | 0.2944 | 0.2796 | 0.3368 | 0.3599 | 0.3319 | 0.3059 |
| u9 | 0.3003 | 0.2912 | 0.3368 | 0.3599 | 0.3319 | 0.3060 |
| u10 | 0.3003 | 0.3029 | 0.3334 | 0.3484 | 0.3348 | 0.3056 |
| u11 | 0.3003 | 0.2970 | 0.3363 | 0.3484 | 0.3348 | 0.3056 |
| u12 | 0.2944 | 0.2970 | 0.3386 | 0.3484 | 0.3657 | 0.4043 |
| u13 | 0.3003 | 0.3029 | 0.3357 | 0.3484 | 0.3657 | 0.4042 |
| u14 | 0.2944 | 0.2796 | 0.3340 | 0.3599 | 0.3657 | 0.4036 |
| u15 | 0.2885 | 0.2796 | 0.3374 | 0.3599 | 0.3657 | 0.4036 |
| u16 | 0.9714 | 0.7222 | 0.6448 | 0.6112 | 0.5875 | 0.5684 |
| u17 | 0.8596 | 0.7397 | 0.6569 | 0.6112 | 0.5876 | 0.5682 |
| u18 | 0.7889 | 0.7455 | 0.7101 | 0.6969 | 0.5876 | 0.5700 |
| u19 | 0.8478 | 0.7339 | 0.6979 | 0.7026 | 0.5877 | 0.5704 |
| u20 | 0.8242 | 0.7397 | 0.6974 | 0.6969 | 0.6648 | 0.7155 |
| u21 | 0.7771 | 0.7513 | 0.7124 | 0.6969 | 0.6651 | 0.7186 |
| u22 | 0.8360 | 0.7455 | 0.6575 | 0.6112 | 0.6968 | 0.7425 |
| u23 | 0.9184 | 0.7339 | 0.6465 | 0.6112 | 0.7018 | 0.7385 |
| u24 | 1.1657 | 1.3046 | 1.3549 | 1.4052 | 0.9102 | 0.9163 |
| u25 | 0.9479 | 1.0833 | 1.1931 | 1.2281 | 0.9102 | 0.9089 |
| u26 | 0.8419 | 0.9785 | 1.0117 | 1.0054 | 0.9780 | 0.9771 |
| u27 | 0.9302 | 1.0134 | 0.9857 | 0.9482 | 0.9842 | 1.0012 |
| u28 | 0.9950 | 0.9901 | 0.9689 | 0.9425 | 1.1892 | 1.1766 |
| u29 | 0.8713 | 0.9610 | 0.9967 | 0.9939 | 1.2411 | 1.2355 |
| u30 | 1.0185 | 1.0658 | 1.1683 | 1.1882 | 1.4707 | 1.4381 |
| u31 | 1.4660 | 1.6424 | 1.6391 | 1.6566 | 1.7274 | 1.6851 |

**Table C.1.11** 4096QAM Definition Table for Code Rates 8/15-13/15

| u/CR | 8/15 | 9/15 | 10/15 | 11/15 | 12/15 | 13/15 |
|---|---|---|---|---|---|---|
| u0 | 0.0501 | 0.0415 | 0.0397 | 0.0253 | 0.0262 | 0.0176 |
| u1 | 0.0553 | 0.0478 | 0.0397 | 0.0285 | 0.0262 | 0.0487 |
| u2 | 0.0562 | 0.0592 | 0.0659 | 0.0844 | 0.0828 | 0.0781 |
| u3 | 0.0562 | 0.0592 | 0.0659 | 0.0848 | 0.0842 | 0.1080 |
| u4 | 0.1677 | 0.1656 | 0.1443 | 0.1460 | 0.1337 | 0.1399 |
| u5 | 0.1687 | 0.1663 | 0.1453 | 0.1460 | 0.1389 | 0.1713 |
| u6 | 0.1687 | 0.1663 | 0.1819 | 0.2078 | 0.1887 | 0.2053 |
| u7 | 0.1718 | 0.1663 | 0.1826 | 0.2078 | 0.2018 | 0.2378 |
| u8 | 0.2963 | 0.2861 | 0.2591 | 0.2708 | 0.2466 | 0.2720 |
| u9 | 0.2963 | 0.2863 | 0.2591 | 0.2708 | 0.2675 | 0.3076 |
| u10 | 0.2963 | 0.2877 | 0.3128 | 0.3360 | 0.3096 | 0.3412 |
| u11 | 0.2968 | 0.2877 | 0.3128 | 0.3360 | 0.3393 | 0.3754 |
| u12 | 0.4234 | 0.4144 | 0.3872 | 0.4051 | 0.3796 | 0.4156 |
| u13 | 0.4240 | 0.4178 | 0.3872 | 0.4052 | 0.4118 | 0.4522 |
| u14 | 0.4248 | 0.4204 | 0.4549 | 0.4742 | 0.4506 | 0.4893 |
| u15 | 0.4248 | 0.4204 | 0.4549 | 0.4742 | 0.4897 | 0.5260 |
| u16 | 0.5584 | 0.5352 | 0.5290 | 0.5417 | 0.5296 | 0.5643 |
| u17 | 0.5590 | 0.5370 | 0.5302 | 0.5446 | 0.5712 | 0.6051 |
| u18 | 0.5679 | 0.5673 | 0.6069 | 0.6118 | 0.6136 | 0.6469 |
| u19 | 0.5729 | 0.5683 | 0.6081 | 0.6209 | 0.6586 | 0.6885 |
| u20 | 0.7078 | 0.6848 | 0.6911 | 0.6857 | 0.7060 | 0.7336 |
| u21 | 0.7090 | 0.6848 | 0.6969 | 0.7107 | 0.7544 | 0.7790 |
| u22 | 0.7610 | 0.7694 | 0.7787 | 0.7734 | 0.8043 | 0.8255 |
| u23 | 0.7640 | 0.7838 | 0.8012 | 0.8174 | 0.8624 | 0.8776 |
| u24 | 0.8966 | 0.8808 | 0.8802 | 0.8791 | 0.9152 | 0.9254 |
| u25 | 0.8979 | 0.9039 | 0.9248 | 0.9425 | 0.9718 | 0.9749 |
| u26 | 1.0135 | 1.0050 | 1.0037 | 1.0131 | 1.0325 | 1.0276 |
| u27 | 1.0393 | 1.0619 | 1.0861 | 1.0904 | 1.1017 | 1.0870 |
| u28 | 1.1817 | 1.1797 | 1.1870 | 1.1787 | 1.1756 | 1.1474 |
| u29 | 1.2459 | 1.2898 | 1.2894 | 1.2766 | 1.2541 | 1.2121 |
| u30 | 1.4232 | 1.4381 | 1.4122 | 1.3852 | 1.3405 | 1.2835 |
| u31 | 1.6336 | 1.6223 | 1.5629 | 1.5162 | 1.4431 | 1.3644 |

## C.2 CONSTELLATION FIGURES

The constellations are shown graphically in Figure C.2.1 for QPSK, Figure C.2.2 for 16QAM, Figure C.2.3 for 64QAM, Figure C.2.4 for 256QAM, Figure C.2.5 for 1024QAM and Figure C.2.6 for 4096QAM.

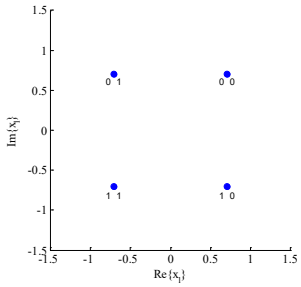


**Figure C.2.1** Constellation of QPSK.

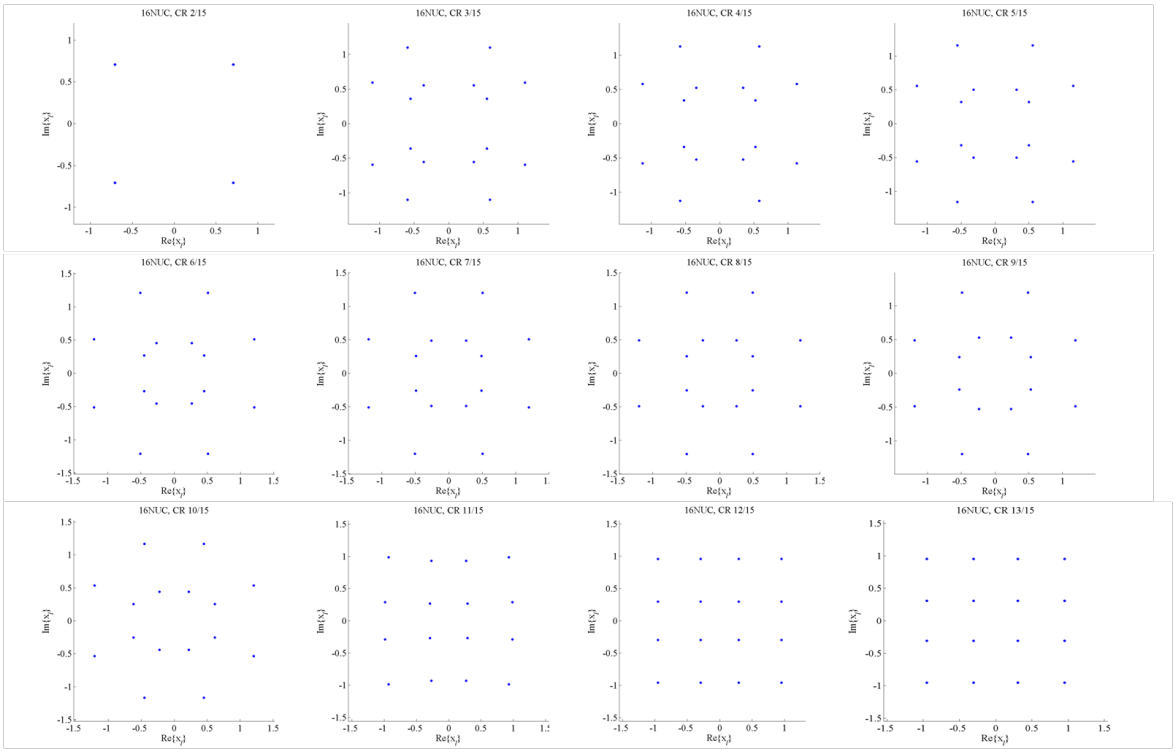


**Figure C.2.2** Constellations of 16QAM.

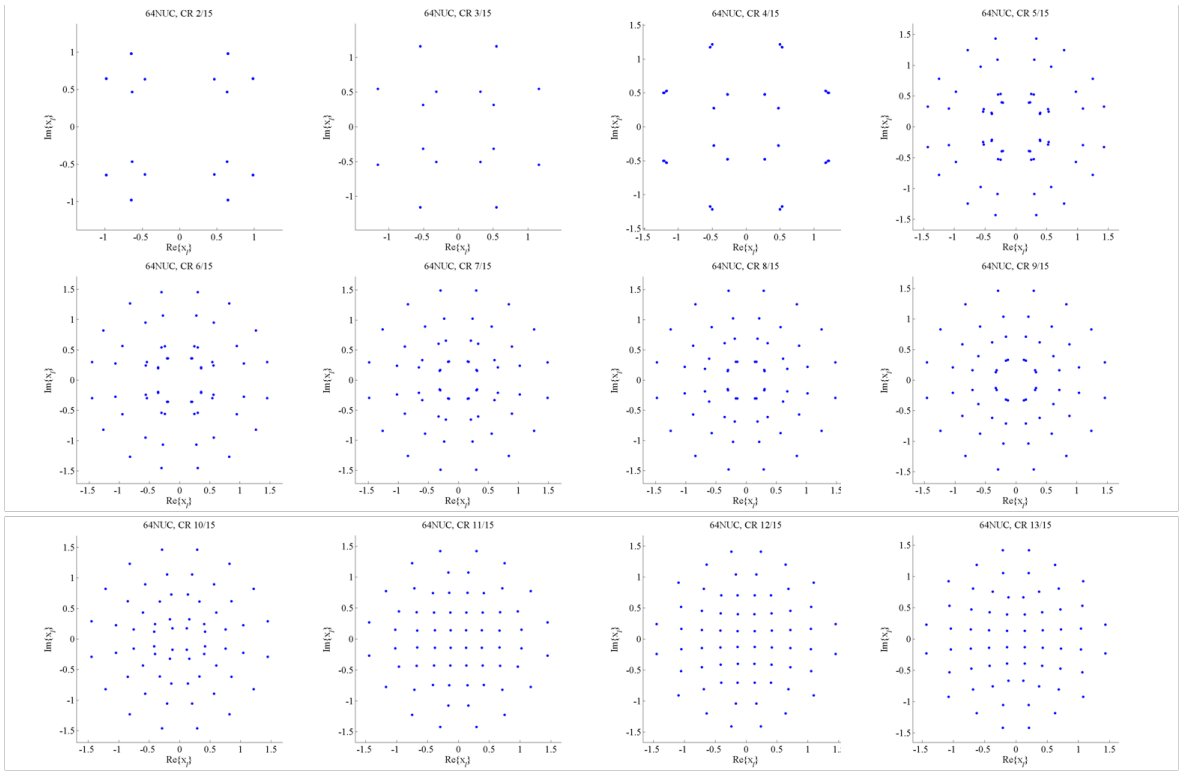


**Figure C.2.3** Constellations of 64QAM.

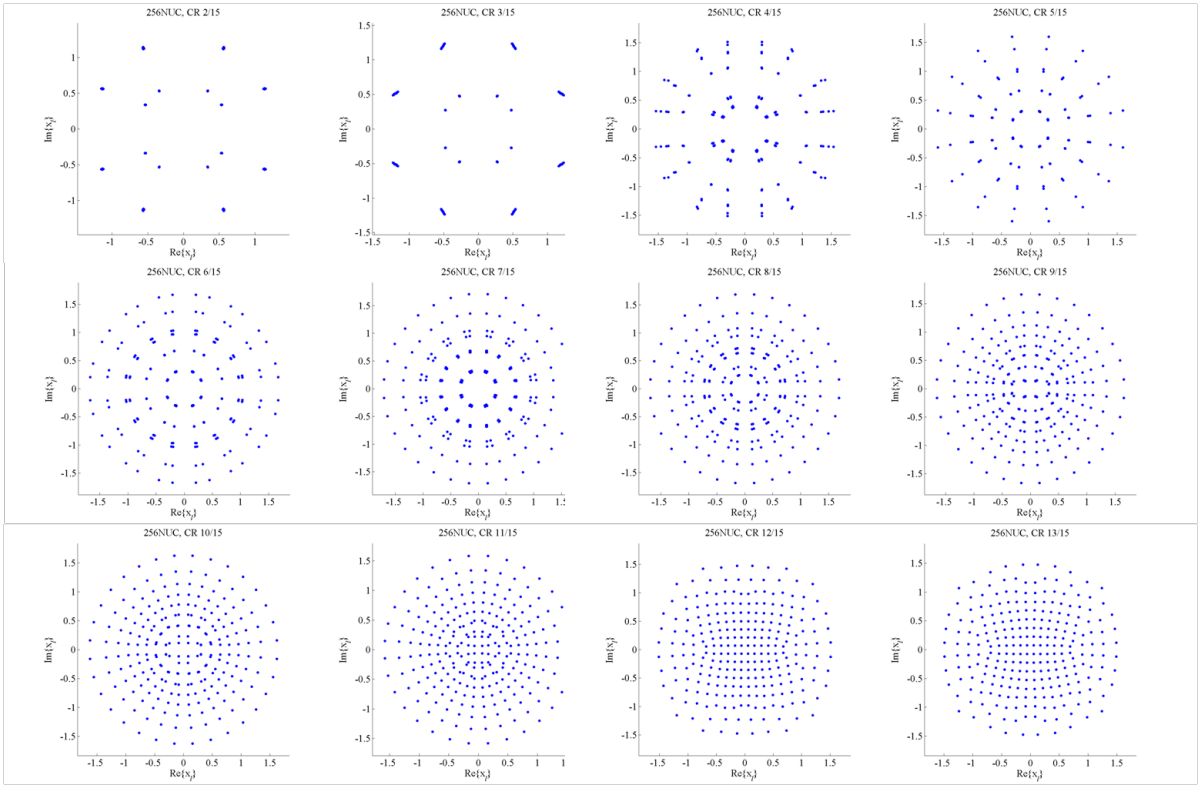


**Figure C.2.4** Constellations of 256QAM.

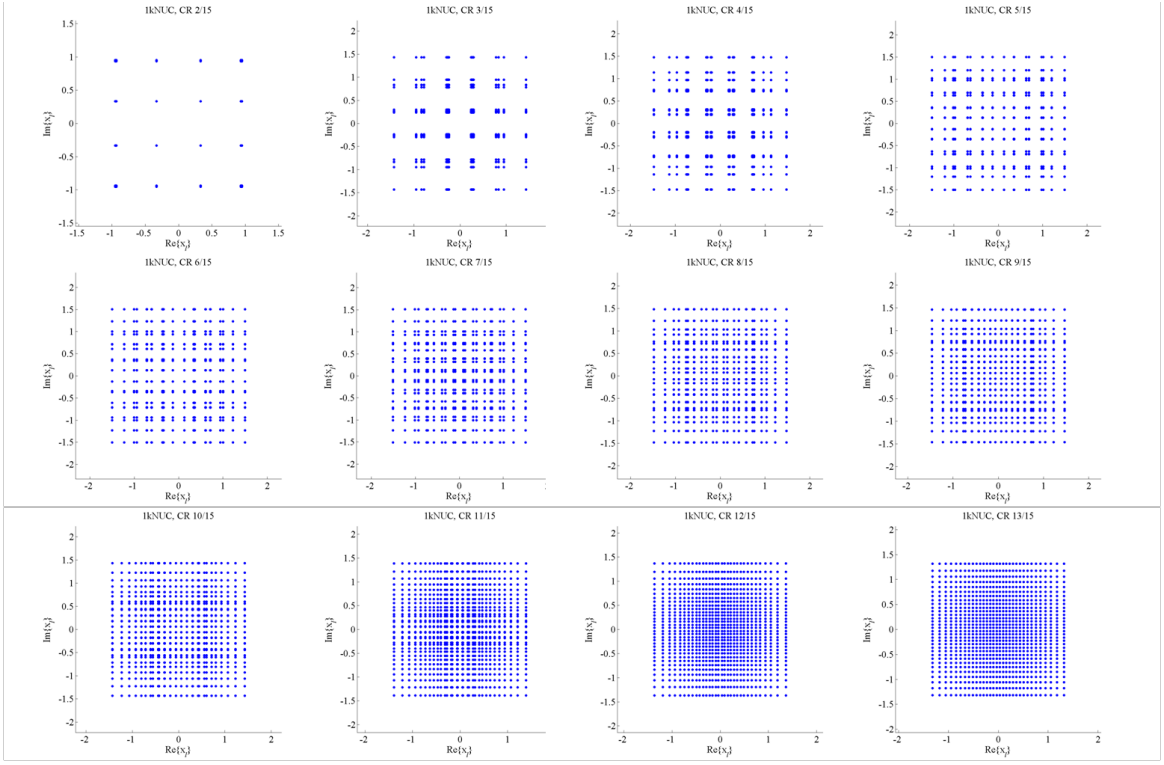


**Figure C.2.5** Constellations of 1024QAM.

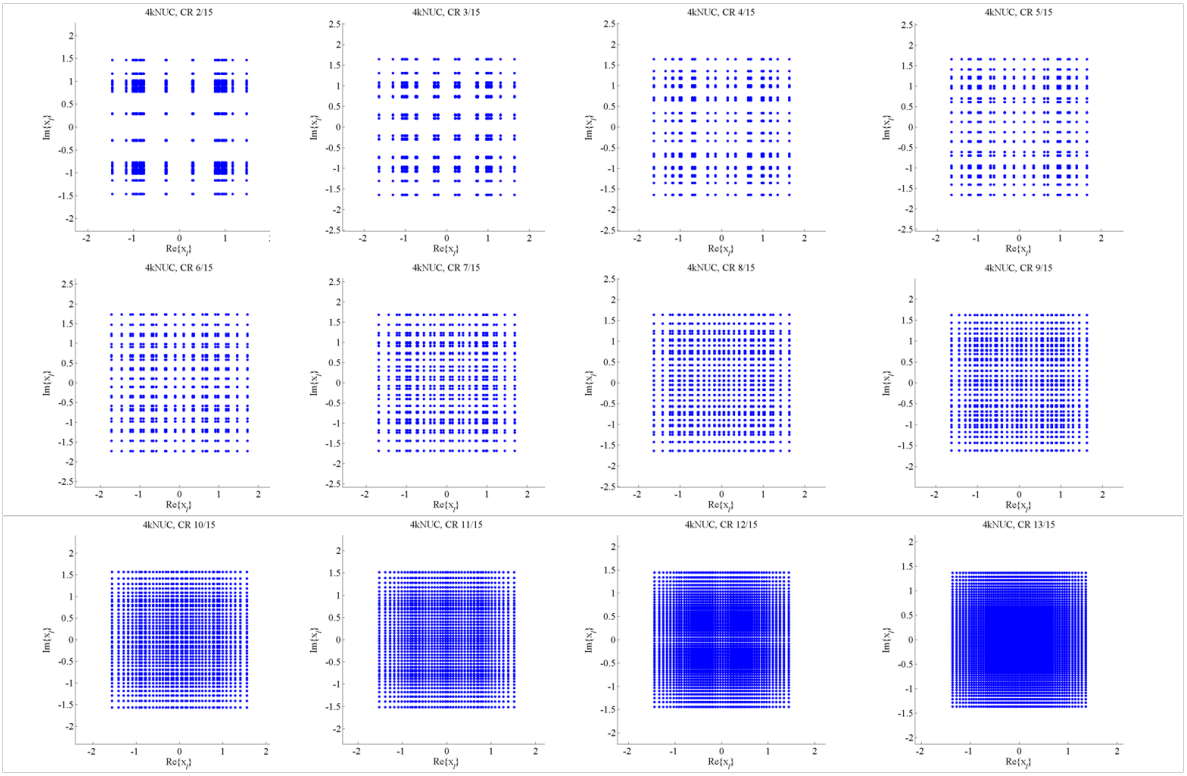


**Figure C.2.6** Constellations of 4096QAM.

## C.3 CONSTELLATION LABELING

The bit labeling of the non-uniform constellations shall be defined according to the following four tables. The real and imaginary parts shall use the same bit labeling.

**Table C.3.1** Constellation Mapping for the Real Part of 1024QAM

| | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| $y_{1,s}$ | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| $y_{3,s}$ | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| $y_{5,s}$ | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 0 |
| $y_{7,s}$ | 0 | 0 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 1 | 0 | 0 |
| $y_{9,s}$ | 0 | 1 | 1 | 0 | 0 | 1 | 1 | 0 | 0 | 1 | 1 | 0 | 0 | 1 | 1 | 0 |
| $Re(z_s)$ | $-u_{15}$ | $-u_{14}$ | $-u_{13}$ | $-u_{12}$ | $-u_{11}$ | $-u_{10}$ | $-u_9$ | $-u_8$ | $-u_7$ | $-u_6$ | $-u_5$ | $-u_4$ | $-u_3$ | $-u_2$ | $-u_1$ | $-u_0$ |
| $y_{1,s}$ | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| $y_{3,s}$ | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| $y_{5,s}$ | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 0 |
| $y_{7,s}$ | 0 | 0 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 1 | 0 | 0 |
| $y_{9,s}$ | 0 | 1 | 1 | 0 | 0 | 1 | 1 | 0 | 0 | 1 | 1 | 0 | 0 | 1 | 1 | 0 |
| $Re(z_s)$ | $u_0$ | $u_1$ | $u_2$ | $u_3$ | $u_4$ | $u_5$ | $u_6$ | $u_7$ | $u_8$ | $u_9$ | $u_{10}$ | $u_{11}$ | $u_{12}$ | $u_{13}$ | $u_{14}$ | $u_{15}$ |

**Table C.3.2** Constellation Mapping for the Imaginary Part of 1024QAM

| | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| $y_{0,s}$ | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| $y_{2,s}$ | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| $y_{4,s}$ | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 0 |
| $y_{6,s}$ | 0 | 0 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 1 | 0 | 0 |
| $y_{8,s}$ | 0 | 1 | 1 | 0 | 0 | 1 | 1 | 0 | 0 | 1 | 1 | 0 | 0 | 1 | 1 | 0 |
| $Im(z_s)$ | $-u_{15}$ | $-u_{14}$ | $-u_{13}$ | $-u_{12}$ | $-u_{11}$ | $-u_{10}$ | $-u_9$ | $-u_8$ | $-u_7$ | $-u_6$ | $-u_5$ | $-u_4$ | $-u_3$ | $-u_2$ | $-u_1$ | $-u_0$ |
| $y_{0,s}$ | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| $y_{2,s}$ | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| $y_{4,s}$ | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 0 |
| $y_{6,s}$ | 0 | 0 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 1 | 0 | 0 |
| $y_{8,s}$ | 0 | 1 | 1 | 0 | 0 | 1 | 1 | 0 | 0 | 1 | 1 | 0 | 0 | 1 | 1 | 0 |
| $Im(z_s)$ | $u_0$ | $u_1$ | $u_2$ | $u_3$ | $u_4$ | $u_5$ | $u_6$ | $u_7$ | $u_8$ | $u_9$ | $u_{10}$ | $u_{11}$ | $u_{12}$ | $u_{13}$ | $u_{14}$ | $u_{15}$ |

**Table C.3.3** Constellation Mapping for the Real Part of 4096QAM

| | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| $y_{1,s}$ | | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| $y_{3,s}$ | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| $y_{5,s}$ | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| $y_{7,s}$ | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 0 |
| $y_{9,s}$ | 0 | 0 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 1 | 0 | 0 |
| $y_{11,s}$ | 0 | 1 | 1 | 0 | 0 | 1 | 1 | 0 | 0 | 1 | 1 | 0 | 0 | 1 | 1 | 0 |
| $Re(z_s)$ | $-u_{31}$ | $-u_{30}$ | $-u_{29}$ | $-u_{28}$ | $-u_{27}$ | $-u_{26}$ | $-u_{25}$ | $-u_{24}$ | $-u_{23}$ | $-u_{22}$ | $-u_{21}$ | $-u_{20}$ | $-u_{19}$ | $-u_{18}$ | $-u_{17}$ | $-u_{16}$ |
| $y_{1,s}$ | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| $y_{3,s}$ | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| $y_{5,s}$ | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| $y_{7,s}$ | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 0 |
| $y_{9,s}$ | 0 | 0 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 1 | 0 | 0 |
| $y_{11,s}$ | 0 | 1 | 1 | 0 | 0 | 1 | 1 | 0 | 0 | 1 | 1 | 0 | 0 | 1 | 1 | 0 |
| $Re(z_s)$ | $-u_{15}$ | $-u_{14}$ | $-u_{13}$ | $-u_{12}$ | $-u_{11}$ | $-u_{10}$ | $-u_{9}$ | $-u_{8}$ | $-u_{7}$ | $-u_{6}$ | $-u_{5}$ | $-u_{4}$ | $-u_{3}$ | $-u_{2}$ | $-u_{1}$ | $-u_{0}$ |
| $y_{1,s}$ | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| $y_{3,s}$ | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| $y_{5,s}$ | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| $y_{7,s}$ | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 0 |
| $y_{9,s}$ | 0 | 0 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 1 | 0 | 0 |
| $y_{11,s}$ | 0 | 1 | 1 | 0 | 0 | 1 | 1 | 0 | 0 | 1 | 1 | 0 | 0 | 1 | 1 | 0 |
| $Re(z_s)$ | $u_{0}$ | $u_{1}$ | $u_{2}$ | $u_{3}$ | $u_{4}$ | $u_{5}$ | $u_{6}$ | $u_{7}$ | $u_{8}$ | $u_{9}$ | $u_{10}$ | $u_{11}$ | $u_{12}$ | $u_{13}$ | $u_{14}$ | $u_{15}$ |
| $y_{1,s}$ | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| $y_{3,s}$ | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| $y_{5,s}$ | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| $y_{7,s}$ | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 0 |
| $y_{9,s}$ | 0 | 0 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 1 | 0 | 0 |
| $y_{11,s}$ | 0 | 1 | 1 | 0 | 0 | 1 | 1 | 0 | 0 | 1 | 1 | 0 | 0 | 1 | 1 | 0 |
| $Re(z_s)$ | $u_{16}$ | $u_{17}$ | $u_{18}$ | $u_{19}$ | $u_{20}$ | $u_{21}$ | $u_{22}$ | $u_{23}$ | $u_{24}$ | $u_{25}$ | $u_{26}$ | $u_{27}$ | $u_{28}$ | $u_{29}$ | $u_{30}$ | $u_{31}$ |

**Table C.3.4** Constellation Mapping for the Imaginary Part of 4096QAM

| | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| $y_{0,s}$ | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| $y_{2,s}$ | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| $y_{4,s}$ | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| $y_{6,s}$ | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 0 |
| $y_{8,s}$ | 0 | 0 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 1 | 0 | 0 |
| $y_{10,s}$ | 0 | 1 | 1 | 0 | 0 | 1 | 1 | 0 | 0 | 1 | 1 | 0 | 0 | 1 | 1 | 0 |
| $Im(z_s)$ | $-u_{31}$ | $-u_{30}$ | $-u_{29}$ | $-u_{28}$ | $-u_{27}$ | $-u_{26}$ | $-u_{25}$ | $-u_{24}$ | $-u_{23}$ | $-u_{22}$ | $-u_{21}$ | $-u_{20}$ | $-u_{19}$ | $-u_{18}$ | $-u_{17}$ | $-u_{16}$ |
| $y_{0,s}$ | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| $y_{2,s}$ | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| $y_{4,s}$ | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| $y_{6,s}$ | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 0 |
| $y_{8,s}$ | 0 | 0 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 1 | 0 | 0 |
| $y_{10,s}$ | 0 | 1 | 1 | 0 | 0 | 1 | 1 | 0 | 0 | 1 | 1 | 0 | 0 | 1 | 1 | 0 |
| $Im(z_s)$ | $-u_{15}$ | $-u_{14}$ | $-u_{13}$ | $-u_{12}$ | $-u_{11}$ | $-u_{10}$ | $-u_9$ | $-u_8$ | $-u_7$ | $-u_6$ | $-u_5$ | $-u_4$ | $-u_3$ | $-u_2$ | $-u^1$ | $-u^0$ |
| $y_{0,s}$ | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| $y_{2,s}$ | 01 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| $y_{4,s}$ | | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| $y_{6,s}$ | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 0 |
| $y_{8,s}$ | 0 | 0 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 1 | 0 | 0 |
| $y_{10,s}$ | 0 | 1 | 1 | 0 | 0 | 1 | 1 | 0 | 0 | 1 | 1 | 0 | 0 | 1 | 1 | 0 |
| $Im(z_s)$ | $u_0$ | $u_1$ | $u_2$ | $u_3$ | $u_4$ | $u_5$ | $u_6$ | $u_7$ | $u_8$ | $u_9$ | $u_{10}$ | $u_{11}$ | $u_{12}$ | $u_{13}$ | $u_{14}$ | $u_{15}$ |
| $y_{0,s}$ | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| $y_{2,s}$ | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| $y_{4,s}$ | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| $y_{6,s}$ | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 0 |
| $y_{8,s}$ | 0 | 0 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 1 | 0 | 0 |
| $y_{10,s}$ | 0 | 1 | 1 | 0 | 0 | 1 | 1 | 0 | 0 | 1 | 1 | 0 | 0 | 1 | 1 | 0 |
| $Im(z_s)$ | $u_{16}$ | $u_{17}$ | $u_{18}$ | $u_{19}$ | $u_{20}$ | $u_{21}$ | $u_{22}$ | $u_{23}$ | $u_{24}$ | $u_{25}$ | $u_{26}$ | $u_{27}$ | $u_{28}$ | $u_{29}$ | $u_{30}$ | $u_{31}$ |

# *Annex D*: Continual Pilot (CP) Patterns

## D.1 REFERENCE AND ADDITIONAL CP INDICES

Table D.1.1 gives the absolute carrier indices for the common CP set $CP_{32}$. Table D.1.2 gives the absolute carrier indices for the common CP set $CP_{16}$. Table D.1.3 gives the absolute carrier indices for the common CP set $CP_{8}$. Table D.1.4 gives the relative carrier indices for the additional scattered pilot bearing continual pilot sets arranged by FFT size and scattered pilot pattern.

Carrier indices specified in this annex represent either absolute carrier indices or relative carrier indices as indicated. Absolute carrier indices are indexed on the maximum possible number of carriers regardless of whether carrier reduction has been configured and hence range from 0 to $NoC_{max} - 1$. Relative carrier indices are indexed on the configured number of carriers (which is a function in part of the configured carrier reduction coefficient) and hence range from 0 to $NoC - 1$. Continual pilots with absolute carrier indices that lie outside the configured range of carriers for transmission shall not be transmitted.

**Table D.1.1** Common CP Absolute Carrier Indices $CP_{32}$

| | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 236 | 316 | 356 | 412 | 668 | 716 | 868 | 1100 | 1228 | 1268 | 1340 | 1396 | 1876 | 1916 | 2140 | 2236 | 2548 | 2644 | 2716 | 2860 |
| 3004 | 3164 | 3236 | 3436 | 3460 | 3700 | 3836 | 4028 | 4124 | 4132 | 4156 | 4316 | 4636 | 5012 | 5132 | 5140 | 5332 | 5372 | 5500 | |
| 5524 | 5788 | 6004 | 6020 | 6092 | 6428 | 6452 | 6500 | 6740 | 7244 | 7316 | 7372 | 7444 | 7772 | 7844 | 7924 | 8020 | 8164 | 8308 | |
| 8332 | 8348 | 8788 | 8804 | 9116 | 9140 | 9292 | 9412 | 9436 | 9604 | 10076 | 10204 | 10340 | 10348 | 10420 | 10660 | 10684 | | | |
| 10708 | 11068 | 11132 | 11228 | 11356 | 11852 | 11860 | 11884 | 12044 | 12116 | 12164 | 12268 | 12316 | 12700 | 12772 | | | | | |
| 12820 | 12988 | 13300 | 13340 | 13564 | 13780 | 13868 | 14084 | 14308 | 14348 | 14660 | 14828 | 14876 | 14948 | 15332 | | | | | |
| 15380 | 15484 | 15532 | 15604 | 15764 | 15788 | 15796 | 16292 | 16420 | 16516 | 16580 | 16940 | 16964 | 16988 | 17228 | | | | | |
| 17300 | 17308 | 17444 | 17572 | 18044 | 18212 | 18236 | 18356 | 18508 | 18532 | 18844 | 18860 | 19300 | 19316 | 19340 | | | | | |
| 19484 | 19628 | 19724 | 19804 | 19876 | 20204 | 20276 | 20332 | 20404 | 20908 | 21148 | 21196 | 21220 | 21556 | 21628 | | | | | |
| 21644 | 21860 | 22124 | 22148 | 22276 | 22316 | 22508 | 22516 | 22636 | 23012 | 23332 | 23492 | 23516 | 23524 | 23620 | | | | | |
| 23812 | 23948 | 24188 | 24212 | 24412 | 24484 | 24644 | 24788 | 24932 | 25004 | 25100 | 25412 | 25508 | 25732 | 25772 | | | | | |
| 26252 | 26308 | 26380 | 26420 | 26548 | 26780 | 26932 | 26980 | 27236 | 27292 | 27332 | 27412 | | | | | | | | |

Note: The common set of absolute carrier indices $CP_{32}$ can also be calculated from only half the number of absolute carriers (e.g. absolute carrier indices 236 to 13780 and here defined as $CP_{32,L}$). The right half of $CP_{32}$, that is $CP_{32,R}$ can be generated by reversing and shifting $CP_{32,L}$ to give a mirror image of the first half of $CP_{32}$. This is summarized by the following equations:

$$CP_{32,R}(k) = 27648 - CP_{32,L}(95 - k)$$
$$CP_{32} = \left[CP_{32,L}, CP_{32,R}\right]$$

for $k = 0, 1, \ldots, 95$ where $[a,b]$ indicates concatenation of $a$ and $b$.

**Table D.1.2** Common CP Absolute Carrier Indices $CP_{16}$

| |
|---|
| 118 178 334 434 614 670 938 1070 1274 1358 1502 1618 1730 1918 2062 2078 2318 2566 2666 2750 2894 3010 3214 3250 3622 3686 3886 3962 4082 4166 4394 4558 4646 4718 5038 5170 5210 5342 5534 5614 5926 5942 6058 6134 6350 6410 6650 6782 6934 7154 7330 7438 7666 7742 7802 7894 8146 8258 8470 8494 8650 8722 9022 9118 9254 9422 9650 9670 9814 9902 10102 10166 10454 10598 10778 10822 11062 11138 11254 11318 11666 11758 11810 11974 12106 12242 12394 12502 12706 12866 13126 13190 13274 13466 13618 13666 |

The common set of absolute carrier indices $CP_{16}$ can also be calculated as described in Section 8.1.4.1.

**Table D.1.3** Common CP Absolute Carrier Indices $CP_8$

| |
|---|
| 59 167 307 469 637 751 865 1031 1159 1333 1447 1607 1811 1943 2041 2197 2323 2519 2605 2767 2963 3029 3175 3325 3467 3665 3833 3901 4073 4235 4325 4511 4627 4825 4907 5051 5227 5389 5531 5627 5833 5905 6053 6197 6353 6563 6637 6809 |

The common set of absolute carrier indices $CP_8$ can also be calculated as described in Section 8.1.4.1.

**Table D.1.4** Additional Scattered Pilot Bearing Continual Pilot Relative Carrier Indices for Each FFT Size and Scattered Pilot Pattern Combination

| Pilot Pattern | FFT Size | | |
|---|---|---|---|
| | **32K** | **16K** | **8K** |
| **SP3_2** | 6939 | 3471 | 1731 |
| **SP3_4** | | 3471<br>5778<br>11469 | 1731<br>2886<br>5733 |
| **SP4_2** | | 3460 | 1732 |
| **SP4_4** | | 3460<br>5768<br>11452 | 1732<br>2888<br>5724 |
| **SP6_2** | 6942 | 3462 | 1734 |
| **SP6_4** | | 3462<br>5772<br>11466 | 1734<br>2892<br>5730 |
| **SP8_2** | 6920 | 3464 | 1736 |
| **SP8_4** | | 3464<br>5776<br>11448 | 1736<br>2896<br>5720 |
| **SP12_2** | 6924 | 3468 | 1740 |
| **SP12_4** | | 3468<br>5784<br>11460 | 1740<br>2904<br>5748 |
| **SP16_2** | 6928 | 3472 | 1744 |
| **SP16_4** | | 3472<br>5792<br>11440 | 1744<br>(2912)<br>(5744) |
| **SP24_2** | 6936 | 3480 | |
| **SP24_4** | | 3480<br>5808<br>11496 | |
| **SP32_2** | 6944 | 3488 | (1696) |
| **SP32_4** | | 3488<br>(5824)<br>(11488) | See<br>Table D.1.5 |

Relative carrier indices given in parentheses in Table D.1.4 are not used if $C_{red_coeff}$ is an odd number.

For 8K FFT size with SP32_4, additional CP sets for various values of $C_{red_coeff}$ are given in Table D.1.5.

**Table D.1.5** Additional Scattered Pilot Bearing Continual Pilot Relative Carrier Indices for SP32_4 in 8K FFT

| $C_{red_coeff}$ | | | | |
|---|---|---|---|---|
| **0** | **1** | **2** | **3** | **4** |
| 1696 | none | 1696 | 1696 | 1696 |
| 2880 | | | 2880 | 2880 |
| 5728 | | | | 5728 |

# *Annex E*: Scattered Pilot (SP) Patterns

## E.1 SISO SCATTERED PILOT PATTERNS

The scattered pilot patterns are shown in the figures below.

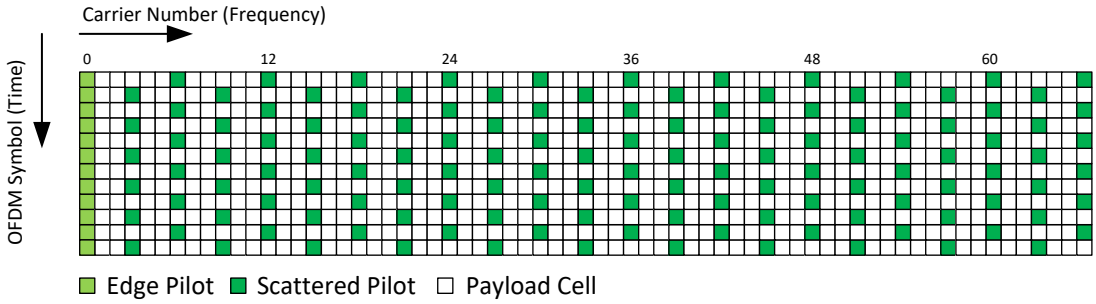


**Figure E.1.1** Scattered pilot pattern SP3_2 (SISO, $D_X = 3$, $D_Y = 2$).

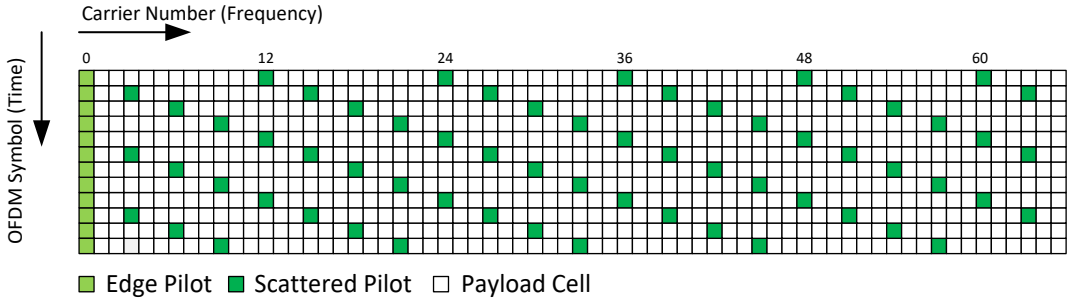


**Figure E.1.2** Scattered pilot pattern SP3_4 (SISO, $D_X = 3$, $D_Y = 4$).

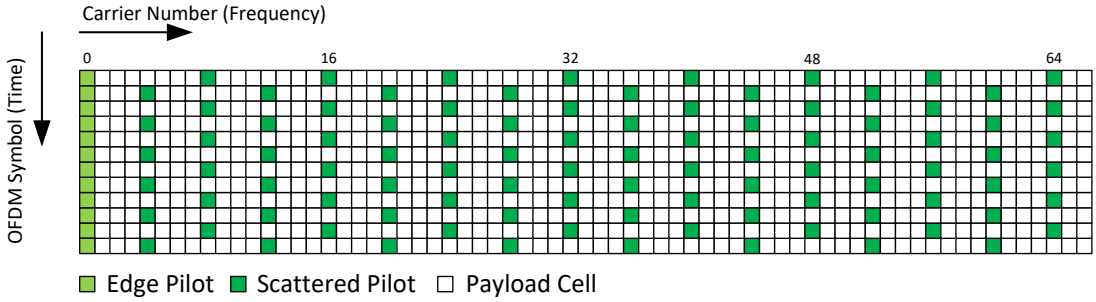


**Figure E.1.3** Scattered pilot pattern SP4_2 (SISO, $D_X = 4$, $D_Y = 2$).

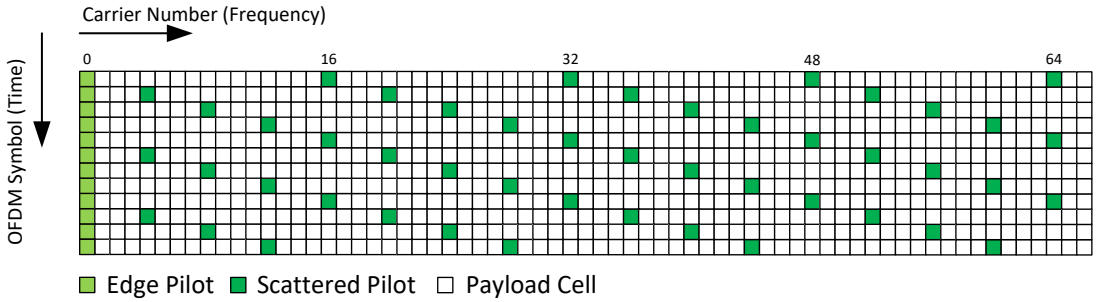


**Figure E.1.4** Scattered pilot pattern SP4_4 (SISO, $D_X = 4$, $D_Y = 4$).

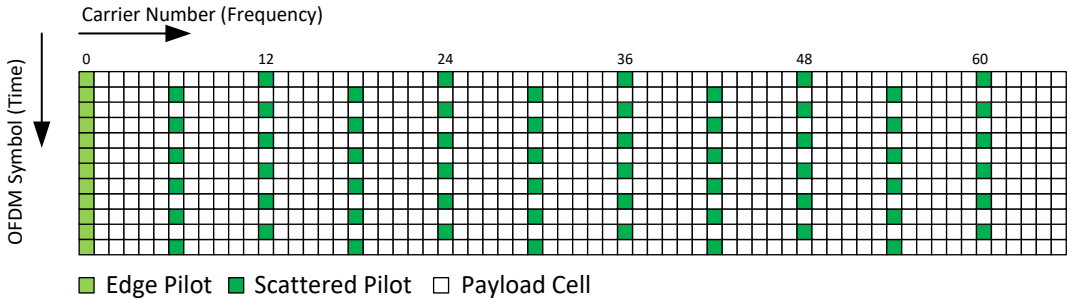


**Figure E.1.5** Scattered pilot pattern SP6_2 (SISO, $D_X = 6$, $D_Y = 2$).

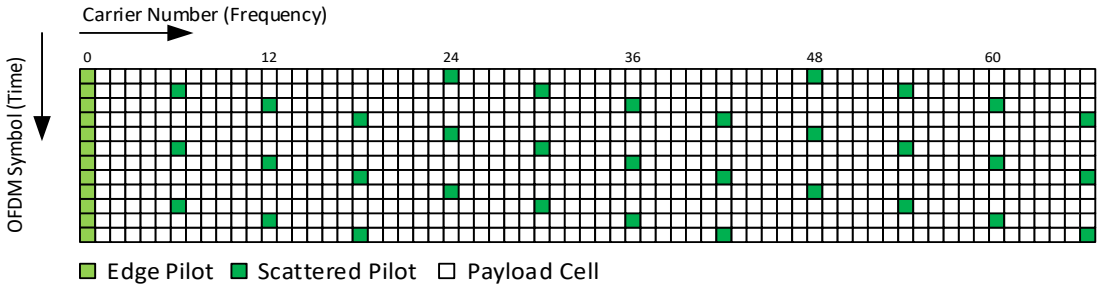


**Figure E.1.6** Scattered pilot pattern SP6_4 (SISO, $D_X = 6$, $D_Y = 4$).

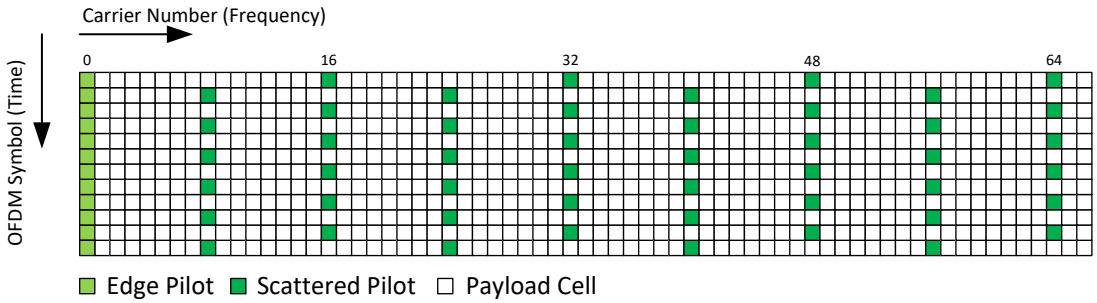


**Figure E.1.7** Scattered pilot pattern SP8_2 (SISO, $D_X = 8$, $D_Y = 2$).

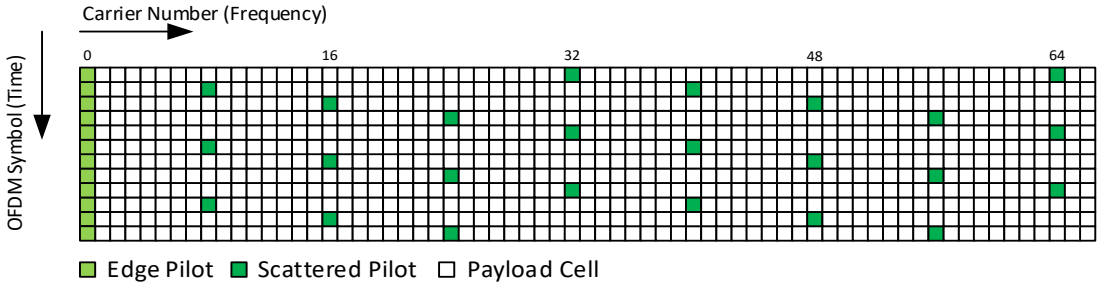


**Figure E.1.8** Scattered pilot pattern SP8_4 (SISO, $D_X = 8$, $D_Y = 4$).

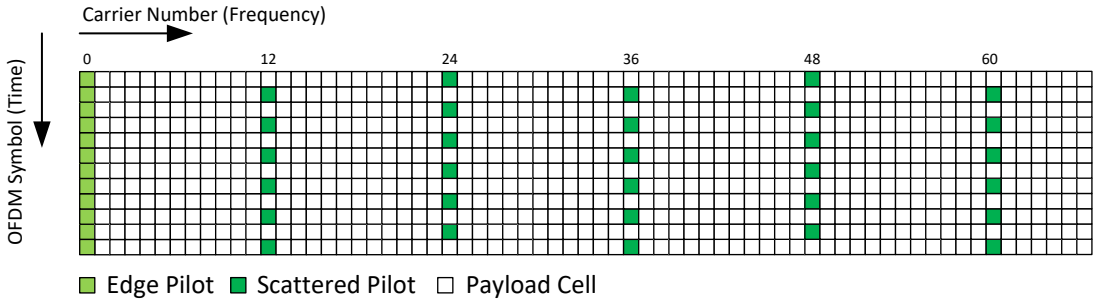


**Figure E.1.9** Scattered pilot pattern SP12_2 (SISO, $D_X = 12$, $D_Y = 2$).

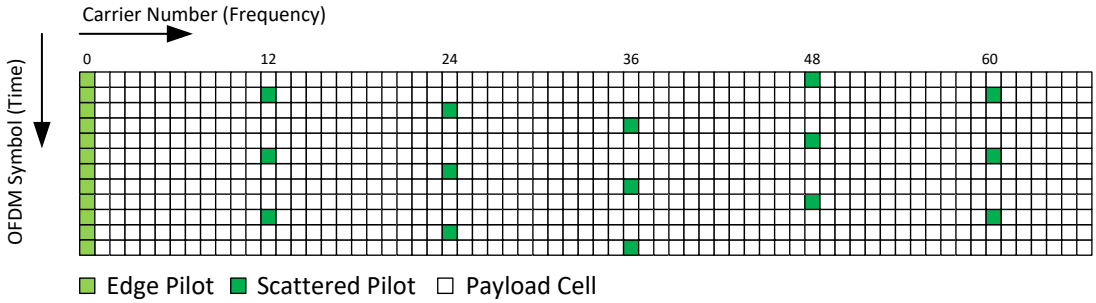


**Figure E.1.10** Scattered pilot pattern SP12_4 (SISO, $D_X = 12$, $D_Y = 4$).

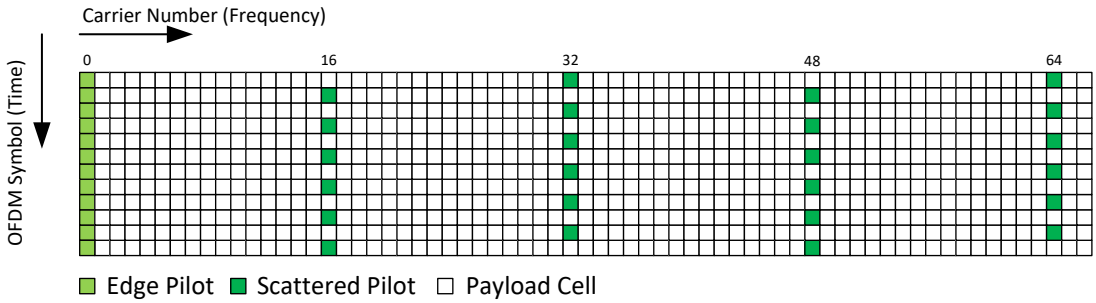


**Figure E.1.11** Scattered pilot pattern SP16_2 (SISO, $D_X = 16$, $D_Y = 2$).

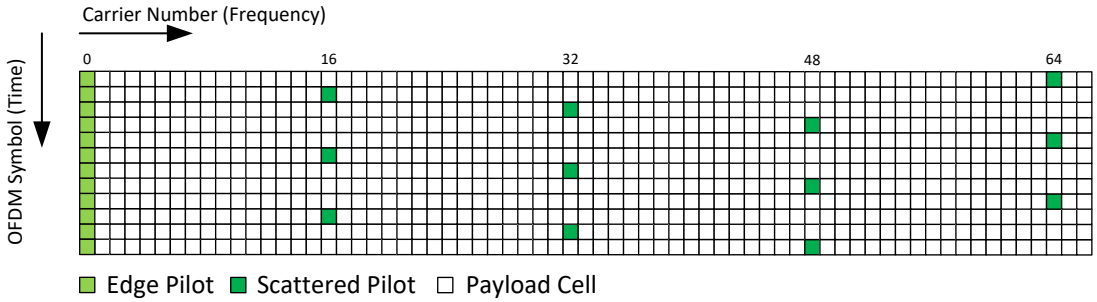


**Figure E.1.12** Scattered pilot pattern SP16_4 (SISO, $D_X = 16$, $D_Y = 4$).

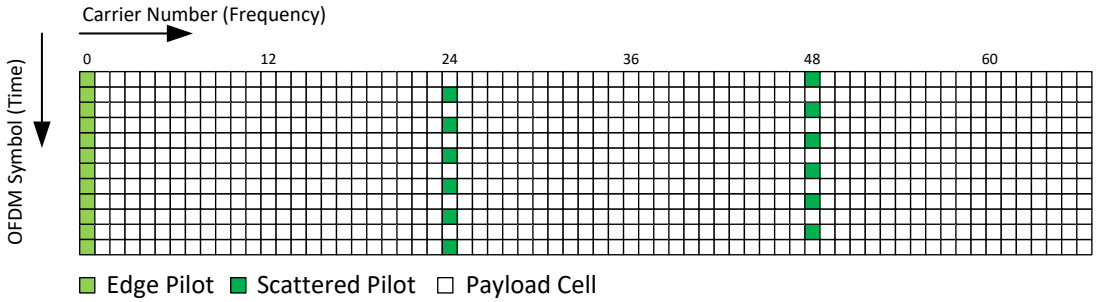


**Figure E.1.13** Scattered pilot pattern SP24_2 (SISO, $D_X = 24$, $D_Y = 2$).

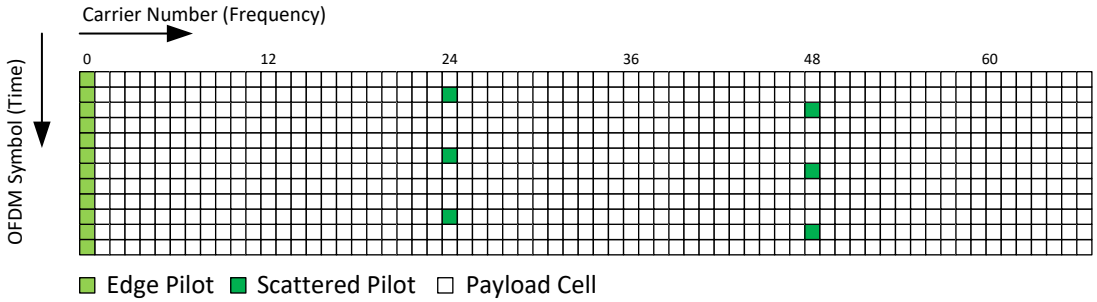


**Figure E.1.14** Scattered pilot pattern SP24_4 (SISO, $D_X = 24$, $D_Y = 4$).

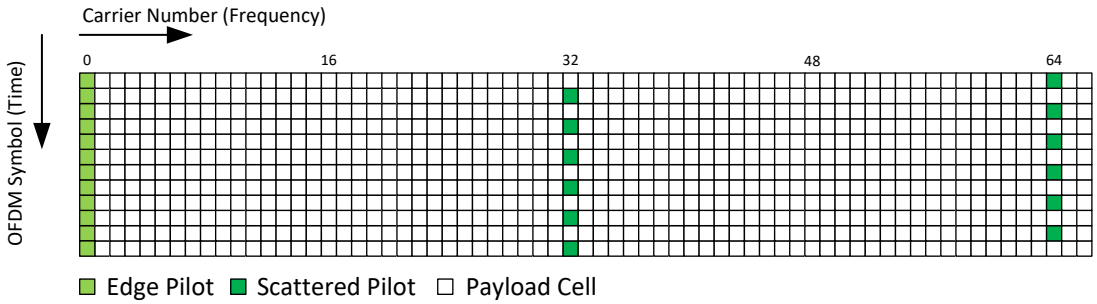


**Figure E.1.15** Scattered pilot pattern SP32_2 (SISO, $D_X = 32$, $D_Y = 2$).

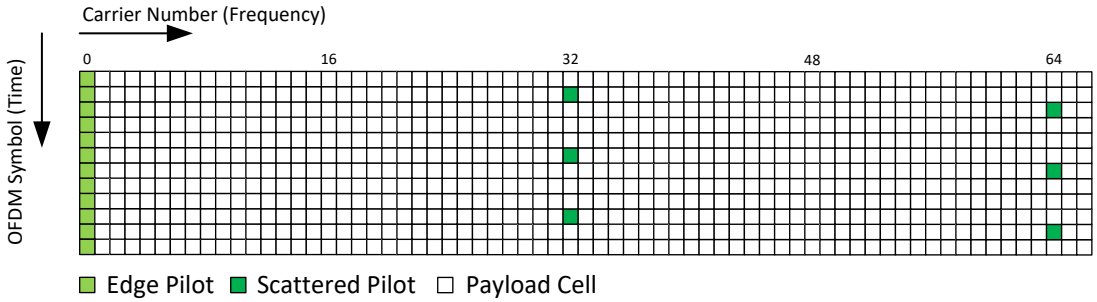


**Figure E.1.16** Scattered pilot pattern SP32_4 (SISO, $D_X = 32$, $D_Y = 4$).

# *Annex F*: Number of Active Data Cells in Subframe Boundary Symbol

## F.1 SUBFRAME BOUNDARY SYMBOL ACTIVE DATA CELL TABLES

The number of active data cells in a subframe boundary symbol (SBS) for various configurations shall be as listed below. Table entries shown in brackets and italicized are for FFT size and scattered pilot pattern combinations that are not allowed (refer to Table 8.3). Tone reservation is not configured in any of the tables in this Annex. When tone reservation is configured, refer to Section 7.2.6.4 to determine the number of active data cells in a subframe boundary symbol. In the following tables **L1D_SPB** is shorthand for **L1D_scattered_pilot_boost.**

**Table F.1.1** Number of Active Data Cells in a SBS when $C_{red_coeff}=0$

| FFT Size | L1D_SPB | Active Data Cells in a Subframe Boundary Symbol | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | SP3_2 | SP3_4 | SP4_2 | SP4_4 | SP6_2 | SP6_4 | SP8_2 | SP8_4 |
| 8K | 0 | 4560 | 4560 | 5136 | 5136 | 5712 | 5712 | 6000 | 6000 |
| | 1 | 4560 | 3904 | 5009 | 4332 | 5456 | 4856 | 5716 | 5168 |
| | 2 | 4123 | 2922 | 4600 | 3467 | 5114 | 4147 | 5398 | 4558 |
| | 3 | 3801 | 2148 | 4278 | 2868 | 4843 | 3588 | 5188 | 4078 |
| | 4 | 3467 | 1534 | 4022 | 2245 | 4629 | 3146 | 4971 | 3697 |
| 16K | 0 | 9120 | 9120 | 10272 | 10272 | 11424 | 11424 | 12000 | 12000 |
| | 1 | 9120 | 7807 | 10017 | 8663 | 10912 | 9708 | 11431 | 10331 |
| | 2 | 8244 | 5841 | 9199 | 6930 | 10225 | 8288 | 10793 | 9109 |
| | 3 | 7601 | 4290 | 8554 | 5731 | 9684 | 7168 | 10375 | 8146 |
| | 4 | 6933 | 3063 | 8043 | 4484 | 9256 | 6282 | 9939 | 7383 |
| 32K | 0 | 18240 | *(18240)* | *N/A* | *N/A* | 22848 | *(22848)* | 24000 | *(24000)* |
| | 1 | 18240 | *(15612)* | *N/A* | *N/A* | 21823 | *(19412)* | 22861 | *(20658)* |
| | 2 | 16488 | *(11678)* | *N/A* | *N/A* | 20449 | *(16570)* | 21585 | *(18212)* |
| | 3 | 15202 | *(8576)* | *N/A* | *N/A* | 19367 | *(14329)* | 20747 | *(16283)* |
| | 4 | 13865 | *(6121)* | *N/A* | *N/A* | 18510 | *(12555)* | 19876 | *(14755)* |

**Table F.1.2** Number of Active Data Cells in a SBS when $C_{red_coeff}=0$

| FFT Size | L1D_SPB | Active Data Cells in a Subframe Boundary Symbol | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | SP12_2 | SP12_4 | SP16_2 | SP16_4 | SP24_2 | SP24_4 | SP32_2 | SP32_4 |
| 8K | 0 | 6288 | 6288 | 6432 | 6432 | *(6576)* | *(6576)* | 6648 | 6648 |
| | 1 | 5976 | 5508 | 6132 | 5691 | *(6297)* | *(5922)* | 6384 | 6064 |
| | 2 | 5729 | 5010 | 5919 | 5252 | *(6123)* | *(5564)* | 6231 | 5757 |
| | 3 | 5533 | 4616 | 5751 | 4906 | *(5986)* | *(5282)* | 6125 | 5515 |
| | 4 | 5379 | 4305 | 5618 | 4633 | *(5877)* | *(5058)* | 6015 | 5324 |
| 16K | 0 | 12576 | 12576 | 12864 | 12864 | 13152 | 13152 | 13296 | 13296 |
| | 1 | 11950 | 11011 | 12262 | 11374 | 12593 | 11834 | 12766 | 12116 |
| | 2 | 11455 | 10010 | 11835 | 10493 | 12243 | 11113 | 12458 | 11497 |
| | 3 | 11064 | 9221 | 11499 | 9798 | 11968 | 10544 | 12245 | 11008 |
| | 4 | 10755 | 8596 | 11233 | 9248 | 11750 | 10094 | 12024 | 10622 |
| 32K | 0 | 25152 | *(25152)* | 25728 | *(25728)* | 26304 | *(26304)* | 26592 | *(26592)* |
| | 1 | 23899 | *(22016)* | 24521 | *(22740)* | 25183 | *(23658)* | 25529 | *(24221)* |
| | 2 | 22907 | *(20010)* | 23667 | *(20974)* | 24483 | *(22211)* | 24913 | *(22976)* |
| | 3 | 22124 | *(18429)* | 22994 | *(19581)* | 23931 | *(21070)* | 24486 | *(21995)* |
| | 4 | 21505 | *(17177)* | 22461 | *(18479)* | 23494 | *(20167)* | 24042 | *(21218)* |

**Table F.1.3** Number of Active Data Cells in a SBS when $C_{red_coeff}=1$

| FFT Size | L1D_SPB | Active Data Cells in a Subframe Boundary Symbol | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | SP3_2 | SP3_4 | SP4_2 | SP4_4 | SP6_2 | SP6_4 | SP8_2 | SP8_4 |
| 8K | 0 | 4496 | 4496 | 5064 | 5064 | 5632 | 5632 | 5916 | 5916 |
| | 1 | 4496 | 3849 | 4938 | 4272 | 5380 | 4788 | 5636 | 5096 |
| | 2 | 4065 | 2881 | 4535 | 3419 | 5042 | 4089 | 5322 | 4494 |
| | 3 | 3748 | 2117 | 4218 | 2828 | 4775 | 3538 | 5116 | 4021 |
| | 4 | 3418 | 1513 | 3966 | 2214 | 4564 | 3102 | 4901 | 3645 |
| 16K | 0 | 8992 | 8992 | 10128 | 10128 | 11264 | 11264 | 11832 | 11832 |
| | 1 | 8992 | 7697 | 9876 | 8541 | 10759 | 9572 | 11271 | 10187 |
| | 2 | 8129 | 5758 | 9070 | 6833 | 10082 | 8171 | 10642 | 8982 |
| | 3 | 7495 | 4229 | 8434 | 5650 | 9549 | 7068 | 10229 | 8032 |
| | 4 | 6835 | 3019 | 7930 | 4420 | 9126 | 6194 | 9800 | 7280 |
| 32K | 0 | 17984 | *(17984)* | *N/A* | *N/A* | 22528 | *(22528)* | 23664 | *(23664)* |
| | 1 | 17984 | *(15393)* | *N/A* | *N/A* | 21517 | *(19140)* | 22541 | *(20369)* |
| | 2 | 16256 | *(11513)* | *N/A* | *N/A* | 20163 | *(16337)* | 21282 | *(17956)* |
| | 3 | 14988 | *(8454)* | *N/A* | *N/A* | 19095 | *(14127)* | 20456 | *(16054)* |
| | 4 | 13669 | *(6033)* | *N/A* | *N/A* | 18250 | *(12378)* | 19597 | *(14548)* |

**Table F.1.4** Number of Active Data Cells in a SBS when $C_{red_coeff}=1$

| FFT Size | L1D_SPB | Active Data Cells in a Subframe Boundary Symbol | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | SP12_2 | SP12_4 | SP16_2 | SP16_4 | SP24_2 | SP24_4 | SP32_2 | SP32_4 |
| 8K | 0 | 6200 | 6200 | 6342 | 6342 | *(6484)* | *(6484)* | 6555 | 6555 |
| | 1 | 5892 | 5431 | 6046 | 5608 | *(6209)* | *(5839)* | 6294 | 5971 |
| | 2 | 5648 | 4940 | 5836 | 5173 | *(6038)* | *(5486)* | 6142 | 5664 |
| | 3 | 5456 | 4552 | 5671 | 4831 | *(5902)* | *(5208)* | 6037 | 5422 |
| | 4 | 5304 | 4245 | 5540 | 4559 | *(5795)* | *(4988)* | 5928 | 5231 |
| 16K | 0 | 12400 | 12400 | 12684 | 12684 | 12968 | 12968 | 13110 | 13110 |
| | 1 | 11783 | 10857 | 12090 | 11215 | 12416 | 11668 | 12587 | 11941 |
| | 2 | 11294 | 9870 | 11669 | 10346 | 12072 | 10957 | 12284 | 11327 |
| | 3 | 10909 | 9091 | 11338 | 9661 | 11800 | 10397 | 12074 | 10844 |
| | 4 | 10604 | 8475 | 11075 | 9118 | 11585 | 9953 | 11856 | 10461 |
| 32K | 0 | 24800 | *(24800)* | 25368 | *(25368)* | 25936 | *(25936)* | 26220 | *(26220)* |
| | 1 | 23564 | *(21707)* | 24178 | *(22422)* | 24830 | *(23327)* | 25172 | *(23882)* |
| | 2 | 22586 | *(19730)* | 23336 | *(20680)* | 24140 | *(21900)* | 24564 | *(22654)* |
| | 3 | 21815 | *(18170)* | 22672 | *(19307)* | 23596 | *(20775)* | 24143 | *(21687)* |
| | 4 | 21204 | *(16936)* | 22146 | *(18220)* | 23165 | *(19885)* | 23705 | *(20921)* |

**Table F.1.5** Number of Active Data Cells in a SBS when $C_{red_coeff}=2$

| FFT Size | L1D_SPB | Active Data Cells in a Subframe Boundary Symbol | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | SP3_2 | SP3_4 | SP4_2 | SP4_4 | SP6_2 | SP6_4 | SP8_2 | SP8_4 |
| 8K | 0 | 4433 | 4433 | 4993 | 4993 | 5553 | 5553 | 5833 | 5833 |
| | 1 | 4433 | 3796 | 4869 | 4212 | 5304 | 4720 | 5557 | 5024 |
| | 2 | 4008 | 2841 | 4472 | 3371 | 4971 | 4032 | 5247 | 4432 |
| | 3 | 3695 | 2088 | 4158 | 2788 | 4708 | 3488 | 5044 | 3964 |
| | 4 | 3371 | 1492 | 3910 | 2183 | 4500 | 3058 | 4833 | 3595 |
| 16K | 0 | 8867 | 8867 | 9987 | 9987 | 11107 | 11107 | 11667 | 11667 |
| | 1 | 8867 | 7591 | 9739 | 8422 | 10609 | 9438 | 11114 | 10045 |
| | 2 | 8016 | 5679 | 8943 | 6738 | 9942 | 8058 | 10494 | 8857 |
| | 3 | 7391 | 4172 | 8316 | 5572 | 9416 | 6970 | 10087 | 7920 |
| | 4 | 6741 | 2979 | 7820 | 4360 | 8999 | 6108 | 9664 | 7179 |
| 32K | 0 | 17734 | *(17734)* | *N/A* | *N/A* | 22214 | *(22214)* | 23334 | *(23334)* |
| | 1 | 17734 | *(15179)* | *N/A* | *N/A* | 21217 | *(18873)* | 22227 | *(20085)* |
| | 2 | 16031 | *(11354)* | *N/A* | *N/A* | 19882 | *(16110)* | 20986 | *(17707)* |
| | 3 | 14780 | *(8339)* | *N/A* | *N/A* | 18829 | *(13932)* | 20171 | *(15831)* |
| | 4 | 13480 | *(5951)* | *N/A* | *N/A* | 17996 | *(12207)* | 19324 | *(14347)* |

**Table F.1.6** Number of Active Data Cells in a SBS when $C_{red_coeff}=2$

| FFT Size | L1D_SPB | Active Data Cells in a Subframe Boundary Symbol | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | SP12_2 | SP12_4 | SP16_2 | SP16_4 | SP24_2 | SP24_4 | SP32_2 | SP32_4 |
| 8K | 0 | 6113 | 6113 | 6253 | 6253 | *(6393)* | *(6393)* | 6463 | 6463 |
| | 1 | 5810 | 5355 | 5961 | 5532 | *(6122)* | *(5757)* | 6207 | 5890 |
| | 2 | 5569 | 4870 | 5754 | 5106 | *(5953)* | *(5409)* | 6058 | 5589 |
| | 3 | 5380 | 4488 | 5591 | 4770 | *(5820)* | *(5135)* | 5955 | 5351 |
| | 4 | 5229 | 4186 | 5462 | 4504 | *(5714)* | *(4918)* | 5848 | 5164 |
| 16K | 0 | 12227 | 12227 | 12507 | 12507 | 12787 | 12787 | 12927 | 12927 |
| | 1 | 11619 | 10706 | 11921 | 11058 | 12243 | 11506 | 12412 | 11780 |
| | 2 | 11137 | 9732 | 11507 | 10202 | 11903 | 10805 | 12113 | 11178 |
| | 3 | 10757 | 8965 | 11180 | 9526 | 11636 | 10252 | 11906 | 10703 |
| | 4 | 10456 | 8358 | 10921 | 8992 | 11424 | 9815 | 11691 | 10328 |
| 32K | 0 | 24454 | *(24454)* | 25014 | *(25014)* | 25574 | *(25574)* | 25854 | *(25854)* |
| | 1 | 23236 | *(21405)* | 23841 | *(22109)* | 24484 | *(23002)* | 24821 | *(23549)* |
| | 2 | 22271 | *(19455)* | 23011 | *(20392)* | 23803 | *(21595)* | 24221 | *(22339)* |
| | 3 | 21511 | *(17918)* | 22356 | *(19038)* | 23267 | *(20486)* | 23806 | *(21385)* |
| | 4 | 20909 | *(16701)* | 21838 | *(17967)* | 22842 | *(19608)* | 23375 | *(20630)* |

**Table F.1.7** Number of Active Data Cells in a SBS when $C_{red_coeff}=3$

| FFT Size | L1D_SPB | Active Data Cells in a Subframe Boundary Symbol | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | SP3_2 | SP3_4 | SP4_2 | SP4_4 | SP6_2 | SP6_4 | SP8_2 | SP8_4 |
| 8K | 0 | 4370 | 4370 | 4922 | 4922 | 5474 | 5474 | 5750 | 5750 |
| | 1 | 4370 | 3742 | 4800 | 4152 | 5229 | 4653 | 5478 | 4953 |
| | 2 | 3951 | 2800 | 4408 | 3323 | 4901 | 3974 | 5173 | 4369 |
| | 3 | 3643 | 2058 | 4099 | 2749 | 4641 | 3439 | 4972 | 3908 |
| | 4 | 3323 | 1471 | 3855 | 2152 | 4436 | 3015 | 4764 | 3544 |
| 16K | 0 | 8740 | 8740 | 9844 | 9844 | 10948 | 10948 | 11500 | 11500 |
| | 1 | 8740 | 7482 | 9599 | 8302 | 10457 | 9303 | 10955 | 9901 |
| | 2 | 7901 | 5597 | 8815 | 6642 | 9799 | 7943 | 10344 | 8730 |
| | 3 | 7285 | 4112 | 8197 | 5492 | 9281 | 6870 | 9942 | 7807 |
| | 4 | 6644 | 2936 | 7708 | 4297 | 8870 | 6021 | 9525 | 7076 |
| 32K | 0 | 17480 | *(17480)* | *N/A* | *N/A* | 21896 | *(21896)* | 23000 | *(23000)* |
| | 1 | 17480 | *(14962)* | *N/A* | *N/A* | 20913 | *(18603)* | 21909 | *(19798)* |
| | 2 | 15801 | *(11192)* | *N/A* | *N/A* | 19597 | *(15879)* | 20685 | *(17453)* |
| | 3 | 14568 | *(8219)* | *N/A* | *N/A* | 18560 | *(13732)* | 19882 | *(15604)* |
| | 4 | 13287 | *(5866)* | *N/A* | *N/A* | 17738 | *(12032)* | 19048 | *(14141)* |

**Table F.1.8** Number of Active Data Cells in a SBS when $C_{red_coeff}=3$

| FFT Size | L1D_SPB | Active Data Cells in a Subframe Boundary Symbol | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | SP12_2 | SP12_4 | SP16_2 | SP16_4 | SP24_2 | SP24_4 | SP32_2 | SP32_4 |
| 8K | 0 | 6026 | 6026 | 6164 | 6164 | *(6302)* | *(6302)* | 6371 | 6371 |
| | 1 | 5727 | 5279 | 5876 | 5450 | *(6035)* | *(5675)* | 6117 | 5809 |
| | 2 | 5490 | 4801 | 5672 | 5028 | *(5868)* | *(5333)* | 5970 | 5514 |
| | 3 | 5303 | 4425 | 5512 | 4695 | *(5737)* | *(5062)* | 5868 | 5281 |
| | 4 | 5155 | 4126 | 5385 | 4432 | *(5633)* | *(4848)* | 5762 | 5097 |
| 16K | 0 | 12052 | 12052 | 12328 | 12328 | 12604 | 12604 | 12742 | 12742 |
| | 1 | 11452 | 10552 | 11751 | 10900 | 12068 | 11341 | 12234 | 11606 |
| | 2 | 10977 | 9593 | 11342 | 10056 | 11733 | 10650 | 11940 | 11010 |
| | 3 | 10603 | 8837 | 11020 | 9390 | 11469 | 10106 | 11735 | 10540 |
| | 4 | 10307 | 8238 | 10765 | 8863 | 11260 | 9675 | 11523 | 10168 |
| 32K | 0 | 24104 | *(24104)* | 24656 | *(24656)* | 25208 | *(25208)* | 25484 | *(25484)* |
| | 1 | 22903 | *(21099)* | 23500 | *(21793)* | 24133 | *(22673)* | 24465 | *(23212)* |
| | 2 | 21952 | *(19177)* | 22681 | *(20100)* | 23463 | *(21286)* | 23875 | *(22019)* |
| | 3 | 21203 | *(17661)* | 22036 | *(18766)* | 22934 | *(20193)* | 23466 | *(21079)* |
| | 4 | 20609 | *(16462)* | 21525 | *(17710)* | 22515 | *(19328)* | 23040 | *(20335)* |

**Table F.1.9** Number of Active Data Cells in a SBS when $C_{red_coeff}=4$

| FFT Size | L1D_SPB | Active Data Cells in a Subframe Boundary Symbol | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | SP3_2 | SP3_4 | SP4_2 | SP4_4 | SP6_2 | SP6_4 | SP8_2 | SP8_4 |
| 8K | 0 | 4307 | 4307 | 4851 | 4851 | 5395 | 5395 | 5667 | 5667 |
| | 1 | 4307 | 3688 | 4731 | 4092 | 5154 | 4586 | 5399 | 4881 |
| | 2 | 3894 | 2760 | 4345 | 3275 | 4830 | 3917 | 5098 | 4306 |
| | 3 | 3591 | 2029 | 4040 | 2710 | 4575 | 3390 | 4901 | 3852 |
| | 4 | 3275 | 1450 | 3799 | 2121 | 4372 | 2972 | 4695 | 3493 |
| 16K | 0 | 8614 | 8614 | 9702 | 9702 | 10790 | 10790 | 11334 | 11334 |
| | 1 | 8614 | 7374 | 9461 | 8182 | 10306 | 9169 | 10797 | 9758 |
| | 2 | 7787 | 5517 | 8688 | 6546 | 9658 | 7828 | 10194 | 8604 |
| | 3 | 7180 | 4053 | 8079 | 5413 | 9147 | 6771 | 9799 | 7695 |
| | 4 | 6549 | 2894 | 7597 | 4236 | 8743 | 5934 | 9388 | 6974 |
| 32K | 0 | 17228 | *(17228)* | *N/A* | *N/A* | 21580 | *(21580)* | 22668 | *(22668)* |
| | 1 | 17228 | *(14746)* | *N/A* | *N/A* | 20612 | *(18335)* | 21593 | *(19512)* |
| | 2 | 15573 | *(11031)* | *N/A* | *N/A* | 19315 | *(15651)* | 20387 | *(17202)* |
| | 3 | 14359 | *(8101)* | *N/A* | *N/A* | 18292 | *(13534)* | 19596 | *(15380)* |
| | 4 | 13096 | *(5782)* | *N/A* | *N/A* | 17483 | *(11859)* | 18773 | *(13938)* |

**Table F.1.10** Number of Active Data Cells in a SBS when $C_{red_coeff}=4$

| FFT Size | L1D_SPB | Active Data Cells in a Subframe Boundary Symbol | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | SP12_2 | SP12_4 | SP16_2 | SP16_4 | SP24_2 | SP24_4 | SP32_2 | SP32_4 |
| 8K | 0 | 5939 | 5939 | 6075 | 6075 | *(6211)* | *(6211)* | 6279 | 6279 |
| | 1 | 5644 | 5203 | 5792 | 5375 | *(5948)* | *(5594)* | 6030 | 5728 |
| | 2 | 5411 | 4732 | 5591 | 4961 | *(5784)* | *(5256)* | 5886 | 5438 |
| | 3 | 5227 | 4361 | 5432 | 4635 | *(5654)* | *(4990)* | 5786 | 5210 |
| | 4 | 5081 | 4067 | 5307 | 4377 | *(5552)* | *(4779)* | 5682 | 5030 |
| 16K | 0 | 11878 | 11878 | 12150 | 12150 | 12422 | 12422 | 12558 | 12558 |
| | 1 | 11287 | 10400 | 11581 | 10743 | 11894 | 11178 | 12058 | 11444 |
| | 2 | 10819 | 9455 | 11178 | 9911 | 11564 | 10497 | 11767 | 10860 |
| | 3 | 10450 | 8710 | 10861 | 9255 | 11304 | 9960 | 11566 | 10399 |
| | 4 | 10158 | 8120 | 10609 | 8736 | 11098 | 9536 | 11357 | 10034 |
| 32K | 0 | 23756 | *(23756)* | 24300 | *(24300)* | 24844 | *(24844)* | 25116 | *(25116)* |
| | 1 | 22572 | *(20794)* | 23160 | *(21478)* | 23785 | *(22345)* | 24112 | *(22877)* |
| | 2 | 21636 | *(18900)* | 22354 | *(19810)* | 23124 | *(20979)* | 23530 | *(21702)* |
| | 3 | 20897 | *(17407)* | 21718 | *(18495)* | 22603 | *(19902)* | 23127 | *(20775)* |
| | 4 | 20312 | *(16225)* | 21215 | *(17454)* | 22190 | *(19049)* | 22708 | *(20042)* |

## F.2 CALCULATION OF SUBFRAME BOUNDARY SYMBOL NULL CELLS (INFORMATIVE)

The number of null cells in a subframe boundary symbol can be calculated as follows:

$$N_{Null}^{B} = N_{Data}^{B} - N_{C}^{B}$$

where

$$N_{C}^{B} = \text{ceil}\,(N_{C}^{D} - (N_{SP}^{SBS} - \text{NoC} + N_{C}^{D} + N_{NSP}^{CP}) * (\text{A}_{\text{SP}})^2)$$

with the terms used explained as follows:

- $NoC$ total number of active carriers
- $N_{C}^{D}$ number of active data cells in a data symbol
- $N_{C}^{B}$ number of active data cells in a subframe boundary symbol
- $N_{Null}^{B}$ number of null cells in a subframe boundary symbol
- $N_{Data}^{B}$ total number of data cells (non-pilot cells) including both null and active data cells in a subframe boundary symbol
- $A_{SP}$ scattered pilot amplitude
- $N_{SP}^{SBS}$ number of subframe boundary pilots in a subframe boundary symbol
- $N_{NSP}^{CP}$ number of common continual pilots

# *Annex G*: Tone Reservation Carrier Indices

## G.1 TONE RESERVATION CARRIER INDICES

When tone reservation is used, the set of reserved carriers for PAPR reduction in all symbols (except the first Preamble symbol) depends on the type of symbol and $D_X$. Table G.1.1 shows the table indices corresponding to the set of reserved carriers for PAPR reduction according to each type of symbol. Tone reservation shall never be applied to the first Preamble symbol.

**Table G.1.1** Table Indices Corresponding to the Set of Reserved Carriers for PAPR Reduction According to Each Type of Symbol

| **Symbol Index** | **Preamble Symbol** | | | **Subframe Boundary Symbol** | | **Data Symbol** |
|---|---|---|---|---|---|---|
| | ***l* = 0** | ***0 < l < N<sub>P</sub>*** | | | | |
| ***D<sub>X</sub>*** | **All** | **3, 4, 8** | **6, 12, 16, 24, 32** | **3, 4, 8** | **6, 12, 16, 24, 32** | |
| Set of carriers reserved for PAPR reduction | *N/A* | Table G.1.3 | Table G.1.2 | Table G.1.3 | Table G.1.2 | Table G.1.2 |

Carrier indices specified in this Annex represent absolute carrier indices. Absolute carrier indices are indexed on the maximum possible number of carriers regardless of whether carrier reduction has been configured and hence range from 0 to $NoC_{max} - 1$.

**Table G.1.2** Set of Carriers Reserved for PAPR reduction for All Symbols Except the First Preamble Symbol, the Other ($N_P$ – 1) Preamble Symbols of $D_X$= 3, $D_X$= 4, and $D_X$= 8, and Subframe Boundary Symbols of $D_X$= 3, $D_X$= 4, and $D_X$= 8

| FFT (# of Reserved tones) | TR Carrier Indices |
|---|---|
| **8k (72)** | 250, 386, 407, 550, 591, 717, 763, 787, 797, 839, 950, 1090, 1105, 1199, 1738, 1867, 1903, 1997, 2114, 2260, 2356, 2427, 2428, 2444, 2452, 2475, 2564, 2649, 2663, 2678, 2740, 2777, 2819, 2986, 3097, 3134, 3253, 3284, 3323, 3442, 3596, 3694, 3719, 3751, 3763, 3836, 4154, 4257, 4355, 4580, 4587, 4678, 4805, 5084, 5126, 5161, 5229, 5321, 5445, 5649, 5741, 5746, 5885, 5918, 6075, 6093, 6319, 6421, 6463, 6511, 6517, 6577 |
| **16k (144)** | 421, 548, 589, 621, 644, 727, 770, 813, 857, 862, 1113, 1187, 1201, 1220, 1393, 1517, 1821, 1899, 1924, 2003, 2023, 2143, 2146, 2290, 2474, 2482, 2597, 2644, 2749, 2818, 2951, 3014, 3212, 3237, 3363, 3430, 3515, 3517, 3745, 3758, 4049, 4165, 4354, 4399, 4575, 4763, 4789, 4802, 4834, 4970, 5260, 5386, 5395, 5402, 5579, 5716, 5734, 5884, 5895, 6073, 6123, 6158, 6212, 6243, 6521, 6593, 6604, 6607, 6772, 6842, 6908, 6986, 7220, 7331, 7396, 7407, 7588, 7635, 7665, 7893, 7925, 7949, 8019, 8038, 8167, 8289, 8295, 8338, 8549, 8555, 8660, 8857, 8925, 9007, 9057, 9121, 9364, 9375, 9423, 9446, 9479, 9502, 9527, 9860, 9919, 9938, 10138, 10189, 10191, 10275, 10333, 10377, 10988, 11109, 11261, 11266, 11362, 11390, 11534, 11623, 11893, 11989, 12037, 12101, 12119, 12185, 12254, 12369, 12371, 12380, 12401, 12586, 12597, 12638, 12913, 12974, 13001, 13045, 13052, 13111, 13143, 13150, 13151, 13300 |
| **32K (288)** | 803, 805, 811, 901, 1001, 1027, 1245, 1258, 1318, 1478, 1507, 1509, 1556, 1577, 1655, 1742, 1978, 2001, 2056, 2110, 2164, 2227, 2305, 2356, 2408, 2522, 2563, 2780, 2805, 2879, 3010, 3019, 3128, 3389, 3649, 3730, 3873, 4027, 4066, 4087, 4181, 4246, 4259, 4364, 4406, 4515, 4690, 4773, 4893, 4916, 4941, 4951, 4965, 5165, 5222, 5416, 5638, 5687, 5729, 5930, 5997, 6005, 6161, 6218, 6292, 6344, 6370, 6386, 6505, 6974, 7079, 7114, 7275, 7334, 7665, 7765, 7868, 7917, 7966, 8023, 8055, 8089, 8091, 8191, 8374, 8495, 8651, 8690, 8755, 8821, 9139, 9189, 9274, 9561, 9611, 9692, 9711, 9782, 9873, 9964, 10011, 10209, 10575, 10601, 10623, 10690, 10967, 11045, 11083, 11084, 11090, 11128, 11153, 11530, 11737, 11829, 11903, 11907, 11930, 11942, 12356, 12429, 12484, 12547, 12562, 12605, 12767, 12863, 13019, 13052, 13053, 13167, 13210, 13244, 13259, 13342, 13370, 13384, 13447, 13694, 13918, 14002, 14077, 14111, 14216, 14243, 14270, 14450, 14451, 14456, 14479, 14653, 14692, 14827, 14865, 14871, 14908, 15215, 15227, 15284, 15313, 15333, 15537, 15643, 15754, 15789, 16065, 16209, 16213, 16217, 16259, 16367, 16369, 16646, 16780, 16906, 16946, 17012, 17167, 17192, 17325, 17414, 17629, 17687, 17746, 17788, 17833, 17885, 17913, 18067, 18089, 18316, 18337, 18370, 18376, 18440, 18550, 18680, 18910, 18937, 19047, 19052, 19117, 19383, 19396, 19496, 19601, 19778, 19797, 20038, 20357, 20379, 20455, 20669, 20707, 20708, 20751, 20846, 20853, 20906, 21051, 21079, 21213, 21267, 21308, 21355, 21523, 21574, 21815, 21893, 21973, 22084, 22172, 22271, 22713, 22905, 23039, 23195, 23303, 23635, 23732, 23749, 23799, 23885, 23944, 24149, 24311, 24379, 24471, 24553, 24585, 24611, 24616, 24621, 24761, 24789, 24844, 24847, 24977, 25015, 25160, 25207, 25283, 25351, 25363, 25394, 25540, 25603, 25647, 25747, 25768, 25915, 25928, 26071, 26092, 26139, 26180, 26209, 26270, 26273, 26278, 26326, 26341, 26392, 26559, 26642, 26776, 26842 |

**Table G.1.3** Set of Carriers Reserved for PAPR reduction in Preamble Symbols of $D_X = 3$, $D_X = 4$, and $D_X = 8$ Except the First Preamble Symbol and in Subframe Boundary Symbols of $D_X = 3$, $D_X = 4$, and $D_X = 8$

| FFT Size | TR Carrier Indices |
|---|---|
| **8k (72)** | 295, 329, 347, 365, 463, 473, 481, 553, 578, 602, 742, 749, 829, 922, 941, 1115, 1123, 1174, 1363, 1394, 1402, 1615, 1657, 1702, 1898, 1910, 1997, 2399, 2506, 2522, 2687, 2735, 3043, 3295, 3389, 3454, 3557, 3647, 3719, 3793, 3794, 3874, 3898, 3970, 4054, 4450, 4609, 4666, 4829, 4855, 4879, 4961, 4969, 5171, 5182, 5242, 5393, 5545, 5567, 5618, 5630, 5734, 5861, 5897, 5987, 5989, 6002, 6062, 6074, 6205, 6334, 6497 |
| **16k (144)** | 509, 739, 770, 890, 970, 989, 1031, 1033, 1121, 1223, 1231, 1285, 1526, 1559, 1603, 1615, 1690, 1771, 1903, 1910, 1958, 2033, 2146, 2225, 2302, 2306, 2345, 2447, 2477, 2561, 2578, 2597, 2635, 2654, 2687, 2891, 2938, 3029, 3271, 3479, 3667, 3713, 3791, 3977, 4067, 4150, 4217, 4387, 4501, 4541, 4657, 4733, 4742, 4963, 5011, 5149, 5311, 5362, 5491, 5531, 5609, 5722, 5747, 5798, 5842, 5881, 5959, 5983, 6059, 6166, 6178, 6214, 6230, 6382, 6557, 6625, 6811, 6881, 6994, 7261, 7535, 7546, 7711, 7897, 7898, 7918, 7997, 8125, 8398, 8483, 8530, 8686, 8731, 8855, 9001, 9026, 9110, 9206, 9223, 9325, 9466, 9493, 9890, 9893, 10537, 10570, 10691, 10835, 10837, 11098, 11126, 11146, 11198, 11270, 11393, 11629, 11657, 11795, 11867, 11909, 11983, 12046, 12107, 12119, 12353, 12482, 12569, 12575, 12662, 12691, 12739, 12787, 12902, 12917, 12985, 13010, 13022, 13073, 13102, 13141, 13159, 13225, 13255, 13303 |
| **32K (288)** | 793, 884, 899, 914, 1004, 1183, 1198, 1276, 1300, 1339, 1348, 1444, 1487, 1490, 1766, 1870, 1903, 1909, 1961, 2053, 2092, 2099, 2431, 2572, 2578, 2618, 2719, 2725, 2746, 2777, 2798, 2891, 2966, 2972, 3023, 3037, 3076, 3257, 3284, 3326, 3389, 3425, 3454, 3523, 3602, 3826, 3838, 3875, 3955, 4094, 4126, 4261, 4349, 4357, 4451, 4646, 4655, 4913, 5075, 5083, 5306, 5317, 5587, 5821, 6038, 6053, 6062, 6137, 6268, 6286, 6490, 6517, 6529, 6554, 6593, 6671, 6751, 6827, 6845, 7043, 7111, 7147, 7196, 7393, 7451, 7475, 7517, 7750, 7769, 7780, 8023, 8081, 8263, 8290, 8425, 8492, 8939, 8986, 9113, 9271, 9298, 9343, 9455, 9476, 9637, 9821, 9829, 9913, 9953, 9988, 10001, 10007, 10018, 10082, 10172, 10421, 10553, 10582, 10622, 10678, 10843, 10885, 10901, 11404, 11674, 11959, 12007, 12199, 12227, 12290, 12301, 12629, 12631, 12658, 12739, 12866, 12977, 13121, 13294, 13843, 13849, 13852, 13933, 14134, 14317, 14335, 14342, 14407, 14651, 14758, 14815, 14833, 14999, 15046, 15097, 15158, 15383, 15503, 15727, 15881, 16139, 16238, 16277, 16331, 16444, 16490, 16747, 16870, 16981, 17641, 17710, 17714, 17845, 18011, 18046, 18086, 18097, 18283, 18334, 18364, 18431, 18497, 18527, 18604, 18686, 18709, 18731, 18740, 18749, 18772, 18893, 19045, 19075, 19087, 19091, 19099, 19127, 19169, 19259, 19427, 19433, 19450, 19517, 19526, 19610, 19807, 19843, 19891, 20062, 20159, 20246, 20420, 20516, 20530, 20686, 20801, 20870, 20974, 21131, 21158, 21565, 21635, 21785, 21820, 21914, 21926, 22046, 22375, 22406, 22601, 22679, 22699, 22772, 22819, 22847, 22900, 22982, 22987, 23063, 23254, 23335, 23357, 23561, 23590, 23711, 23753, 23902, 24037, 24085, 24101, 24115, 24167, 24182, 24361, 24374, 24421, 24427, 24458, 24463, 24706, 24748, 24941, 25079, 25127, 25195, 25285, 25444, 25492, 25505, 25667, 25682, 25729, 25741, 25765, 25973, 26171, 26180, 26227, 26353, 26381, 26542, 26603, 26651, 26671, 26759, 26804, 26807, 26827 |

# *Annex H*: Preamble Parameters for Bootstrap

## H.1 PREAMBLE STRUCTURE PARAMETER VALUES

The allowed values for **preamble_structure** and corresponding preamble parameter values shall be as shown in Table H.1.1. Note that in the present release of the specification the defined **preamble_structure** values do not make use of L1-Basic Modes 6 and 7.

**Table H.1.1** Meaning of Signaled Values of **preamble_structure**

| preamble_structure | FFT Size | GI Length (samples) | Preamble Pilot $D_X$ | L1-Basic FEC Mode |
|---|---|---|---|---|
| 0 | 8K | 192 | 16 | L1-Basic Mode 1 |
| 1 | 8K | 192 | 16 | L1-Basic Mode 2 |
| 2 | 8K | 192 | 16 | L1-Basic Mode 3 |
| 3 | 8K | 192 | 16 | L1-Basic Mode 4 |
| 4 | 8K | 192 | 16 | L1-Basic Mode 5 |
| 5 | 8K | 384 | 8 | L1-Basic Mode 1 |
| 6 | 8K | 384 | 8 | L1-Basic Mode 2 |
| 7 | 8K | 384 | 8 | L1-Basic Mode 3 |
| 8 | 8K | 384 | 8 | L1-Basic Mode 4 |
| 9 | 8K | 384 | 8 | L1-Basic Mode 5 |
| 10 | 8K | 512 | 6 | L1-Basic Mode 1 |
| 11 | 8K | 512 | 6 | L1-Basic Mode 2 |
| 12 | 8K | 512 | 6 | L1-Basic Mode 3 |
| 13 | 8K | 512 | 6 | L1-Basic Mode 4 |
| 14 | 8K | 512 | 6 | L1-Basic Mode 5 |
| 15 | 8K | 768 | 4 | L1-Basic Mode 1 |
| 16 | 8K | 768 | 4 | L1-Basic Mode 2 |
| 17 | 8K | 768 | 4 | L1-Basic Mode 3 |
| 18 | 8K | 768 | 4 | L1-Basic Mode 4 |
| 19 | 8K | 768 | 4 | L1-Basic Mode 5 |
| 20 | 8K | 1024 | 3 | L1-Basic Mode 1 |
| 21 | 8K | 1024 | 3 | L1-Basic Mode 2 |
| 22 | 8K | 1024 | 3 | L1-Basic Mode 3 |
| 23 | 8K | 1024 | 3 | L1-Basic Mode 4 |
| 24 | 8K | 1024 | 3 | L1-Basic Mode 5 |
| 25 | 8K | 1536 | 4 | L1-Basic Mode 1 |
| 26 | 8K | 1536 | 4 | L1-Basic Mode 2 |
| 27 | 8K | 1536 | 4 | L1-Basic Mode 3 |
| 28 | 8K | 1536 | 4 | L1-Basic Mode 4 |
| 29 | 8K | 1536 | 4 | L1-Basic Mode 5 |
| 30 | 8K | 2048 | 3 | L1-Basic Mode 1 |
| 31 | 8K | 2048 | 3 | L1-Basic Mode 2 |

| preamble_structure | FFT Size | GI Length (samples) | Preamble Pilot $D_X$ | L1-Basic FEC Mode |
|---|---|---|---|---|
| 32 | 8K | 2048 | 3 | L1-Basic Mode 3 |
| 33 | 8K | 2048 | 3 | L1-Basic Mode 4 |
| 34 | 8K | 2048 | 3 | L1-Basic Mode 5 |
| 35 | 16K | 192 | 32 | L1-Basic Mode 1 |
| 36 | 16K | 192 | 32 | L1-Basic Mode 2 |
| 37 | 16K | 192 | 32 | L1-Basic Mode 3 |
| 38 | 16K | 192 | 32 | L1-Basic Mode 4 |
| 39 | 16K | 192 | 32 | L1-Basic Mode 5 |
| 40 | 16K | 384 | 16 | L1-Basic Mode 1 |
| 41 | 16K | 384 | 16 | L1-Basic Mode 2 |
| 42 | 16K | 384 | 16 | L1-Basic Mode 3 |
| 43 | 16K | 384 | 16 | L1-Basic Mode 4 |
| 44 | 16K | 384 | 16 | L1-Basic Mode 5 |
| 45 | 16K | 512 | 12 | L1-Basic Mode 1 |
| 46 | 16K | 512 | 12 | L1-Basic Mode 2 |
| 47 | 16K | 512 | 12 | L1-Basic Mode 3 |
| 48 | 16K | 512 | 12 | L1-Basic Mode 4 |
| 49 | 16K | 512 | 12 | L1-Basic Mode 5 |
| 50 | 16K | 768 | 8 | L1-Basic Mode 1 |
| 51 | 16K | 768 | 8 | L1-Basic Mode 2 |
| 52 | 16K | 768 | 8 | L1-Basic Mode 3 |
| 53 | 16K | 768 | 8 | L1-Basic Mode 4 |
| 54 | 16K | 768 | 8 | L1-Basic Mode 5 |
| 55 | 16K | 1024 | 6 | L1-Basic Mode 1 |
| 56 | 16K | 1024 | 6 | L1-Basic Mode 2 |
| 57 | 16K | 1024 | 6 | L1-Basic Mode 3 |
| 58 | 16K | 1024 | 6 | L1-Basic Mode 4 |
| 59 | 16K | 1024 | 6 | L1-Basic Mode 5 |
| 60 | 16K | 1536 | 4 | L1-Basic Mode 1 |
| 61 | 16K | 1536 | 4 | L1-Basic Mode 2 |
| 62 | 16K | 1536 | 4 | L1-Basic Mode 3 |
| 63 | 16K | 1536 | 4 | L1-Basic Mode 4 |
| 64 | 16K | 1536 | 4 | L1-Basic Mode 5 |
| 65 | 16K | 2048 | 3 | L1-Basic Mode 1 |
| 66 | 16K | 2048 | 3 | L1-Basic Mode 2 |
| 67 | 16K | 2048 | 3 | L1-Basic Mode 3 |
| 68 | 16K | 2048 | 3 | L1-Basic Mode 4 |
| 69 | 16K | 2048 | 3 | L1-Basic Mode 5 |
| 70 | 16K | 2432 | 3 | L1-Basic Mode 1 |
| 71 | 16K | 2432 | 3 | L1-Basic Mode 2 |
| 72 | 16K | 2432 | 3 | L1-Basic Mode 3 |
| 73 | 16K | 2432 | 3 | L1-Basic Mode 4 |
| 74 | 16K | 2432 | 3 | L1-Basic Mode 5 |
| 75 | 16K | 3072 | 4 | L1-Basic Mode 1 |
| 76 | 16K | 3072 | 4 | L1-Basic Mode 2 |
| 77 | 16K | 3072 | 4 | L1-Basic Mode 3 |

| preamble_structure | FFT Size | GI Length (samples) | Preamble Pilot $D_X$ | L1-Basic FEC Mode |
|---|---|---|---|---|
| 78 | 16K | 3072 | 4 | L1-Basic Mode 4 |
| 79 | 16K | 3072 | 4 | L1-Basic Mode 5 |
| 80 | 16K | 3648 | 4 | L1-Basic Mode 1 |
| 81 | 16K | 3648 | 4 | L1-Basic Mode 2 |
| 82 | 16K | 3648 | 4 | L1-Basic Mode 3 |
| 83 | 16K | 3648 | 4 | L1-Basic Mode 4 |
| 84 | 16K | 3648 | 4 | L1-Basic Mode 5 |
| 85 | 16K | 4096 | 3 | L1-Basic Mode 1 |
| 86 | 16K | 4096 | 3 | L1-Basic Mode 2 |
| 87 | 16K | 4096 | 3 | L1-Basic Mode 3 |
| 88 | 16K | 4096 | 3 | L1-Basic Mode 4 |
| 89 | 16K | 4096 | 3 | L1-Basic Mode 5 |
| 90 | 32K | 192 | 32 | L1-Basic Mode 1 |
| 91 | 32K | 192 | 32 | L1-Basic Mode 2 |
| 92 | 32K | 192 | 32 | L1-Basic Mode 3 |
| 93 | 32K | 192 | 32 | L1-Basic Mode 4 |
| 94 | 32K | 192 | 32 | L1-Basic Mode 5 |
| 95 | 32K | 384 | 32 | L1-Basic Mode 1 |
| 96 | 32K | 384 | 32 | L1-Basic Mode 2 |
| 97 | 32K | 384 | 32 | L1-Basic Mode 3 |
| 98 | 32K | 384 | 32 | L1-Basic Mode 4 |
| 99 | 32K | 384 | 32 | L1-Basic Mode 5 |
| 100 | 32K | 512 | 24 | L1-Basic Mode 1 |
| 101 | 32K | 512 | 24 | L1-Basic Mode 2 |
| 102 | 32K | 512 | 24 | L1-Basic Mode 3 |
| 103 | 32K | 512 | 24 | L1-Basic Mode 4 |
| 104 | 32K | 512 | 24 | L1-Basic Mode 5 |
| 105 | 32K | 768 | 16 | L1-Basic Mode 1 |
| 106 | 32K | 768 | 16 | L1-Basic Mode 2 |
| 107 | 32K | 768 | 16 | L1-Basic Mode 3 |
| 108 | 32K | 768 | 16 | L1-Basic Mode 4 |
| 109 | 32K | 768 | 16 | L1-Basic Mode 5 |
| 110 | 32K | 1024 | 12 | L1-Basic Mode 1 |
| 111 | 32K | 1024 | 12 | L1-Basic Mode 2 |
| 112 | 32K | 1024 | 12 | L1-Basic Mode 3 |
| 113 | 32K | 1024 | 12 | L1-Basic Mode 4 |
| 114 | 32K | 1024 | 12 | L1-Basic Mode 5 |
| 115 | 32K | 1536 | 8 | L1-Basic Mode 1 |
| 116 | 32K | 1536 | 8 | L1-Basic Mode 2 |
| 117 | 32K | 1536 | 8 | L1-Basic Mode 3 |
| 118 | 32K | 1536 | 8 | L1-Basic Mode 4 |
| 119 | 32K | 1536 | 8 | L1-Basic Mode 5 |
| 120 | 32K | 2048 | 6 | L1-Basic Mode 1 |
| 121 | 32K | 2048 | 6 | L1-Basic Mode 2 |
| 122 | 32K | 2048 | 6 | L1-Basic Mode 3 |
| 123 | 32K | 2048 | 6 | L1-Basic Mode 4 |

| preamble_structure | FFT Size | GI Length (samples) | Preamble Pilot $D_X$ | L1-Basic FEC Mode |
|---|---|---|---|---|
| 124 | 32K | 2048 | 6 | L1-Basic Mode 5 |
| 125 | 32K | 2432 | 6 | L1-Basic Mode 1 |
| 126 | 32K | 2432 | 6 | L1-Basic Mode 2 |
| 127 | 32K | 2432 | 6 | L1-Basic Mode 3 |
| 128 | 32K | 2432 | 6 | L1-Basic Mode 4 |
| 129 | 32K | 2432 | 6 | L1-Basic Mode 5 |
| 130 | 32K | 3072 | 8 | L1-Basic Mode 1 |
| 131 | 32K | 3072 | 8 | L1-Basic Mode 2 |
| 132 | 32K | 3072 | 8 | L1-Basic Mode 3 |
| 133 | 32K | 3072 | 8 | L1-Basic Mode 4 |
| 134 | 32K | 3072 | 8 | L1-Basic Mode 5 |
| 135 | 32K | 3072 | 3 | L1-Basic Mode 1 |
| 136 | 32K | 3072 | 3 | L1-Basic Mode 2 |
| 137 | 32K | 3072 | 3 | L1-Basic Mode 3 |
| 138 | 32K | 3072 | 3 | L1-Basic Mode 4 |
| 139 | 32K | 3072 | 3 | L1-Basic Mode 5 |
| 140 | 32K | 3648 | 8 | L1-Basic Mode 1 |
| 141 | 32K | 3648 | 8 | L1-Basic Mode 2 |
| 142 | 32K | 3648 | 8 | L1-Basic Mode 3 |
| 143 | 32K | 3648 | 8 | L1-Basic Mode 4 |
| 144 | 32K | 3648 | 8 | L1-Basic Mode 5 |
| 145 | 32K | 3648 | 3 | L1-Basic Mode 1 |
| 146 | 32K | 3648 | 3 | L1-Basic Mode 2 |
| 147 | 32K | 3648 | 3 | L1-Basic Mode 3 |
| 148 | 32K | 3648 | 3 | L1-Basic Mode 4 |
| 149 | 32K | 3648 | 3 | L1-Basic Mode 5 |
| 150 | 32K | 4096 | 3 | L1-Basic Mode 1 |
| 151 | 32K | 4096 | 3 | L1-Basic Mode 2 |
| 152 | 32K | 4096 | 3 | L1-Basic Mode 3 |
| 153 | 32K | 4096 | 3 | L1-Basic Mode 4 |
| 154 | 32K | 4096 | 3 | L1-Basic Mode 5 |
| 155 | 32K | 4864 | 3 | L1-Basic Mode 1 |
| 156 | 32K | 4864 | 3 | L1-Basic Mode 2 |
| 157 | 32K | 4864 | 3 | L1-Basic Mode 3 |
| 158 | 32K | 4864 | 3 | L1-Basic Mode 4 |
| 159 | 32K | 4864 | 3 | L1-Basic Mode 5 |
| 160-255 | Reserved | Reserved | Reserved | Reserved |

# *Annex I*: Total Symbol Power

## I.1 PREAMBLE SYMBOL FREQUENCY DOMAIN POWER

The following tables describe the total frequency domain power in Preamble symbols.

**Table I.1.1** Frequency Domain Total Power of the Preamble Symbol ($P_{\text{Preamble,l}}$)

| FFT Size | GI Length (samples) | Pilot Pattern (*Dx*) | $P_{\text{Preamble}}$ (FD total power) | | | | |
|---|---|---|---|---|---|---|---|
| | | | Cred_coeff 0 | Cred_coeff 1 | Cred_coeff 2 | Cred_coeff 3 | Cred_coeff 4 |
| 8K | 192 | 16 | 8240.53 | 8130.20 | 8013.76 | 7897.31 | 7780.87 |
| 8K | 384 | 8 | 8322.93 | 8211.44 | 8093.84 | 7976.24 | 7858.64 |
| 8K | 512 | 6 | 8301.50 | 8190.31 | 8073.00 | 7955.69 | 7838.38 |
| 8K | 768 | 4 | 8094.28 | 7985.96 | 7871.52 | 7757.08 | 7642.65 |
| 8K | 1024 | 3 | 7737.10 | 7633.73 | 7524.25 | 7414.77 | 7305.30 |
| 8K | 1536 | 4 | 8094.28 | 7985.96 | 7871.52 | 7757.08 | 7642.65 |
| 8K | 2048 | 3 | 7737.10 | 7633.73 | 7524.25 | 7414.77 | 7305.30 |
| 16K | 192 | 32 | 16051.13 | 15836.42 | 15603.37 | 15382.54 | 15155.60 |
| 16K | 384 | 16 | 16477.67 | 16257.01 | 16018.01 | 15791.24 | 15558.36 |
| 16K | 512 | 12 | 16583.95 | 16361.81 | 16121.33 | 15893.08 | 15658.71 |
| 16K | 768 | 8 | 16643.58 | 16420.60 | 16179.28 | 15950.19 | 15714.99 |
| 16K | 1024 | 6 | 16601.06 | 16378.66 | 16137.94 | 15909.43 | 15674.81 |
| 16K | 1536 | 4 | 16561.26 | 16339.42 | 16099.24 | 15871.28 | 15637.21 |
| 16K | 2048 | 3 | 16020.04 | 15805.70 | 15573.04 | 15352.59 | 15126.04 |
| 16K | 2432 | 3 | 16020.04 | 15805.70 | 15573.04 | 15352.59 | 15126.04 |
| 16K | 3072 | 4 | 16561.26 | 16339.42 | 16099.24 | 15871.28 | 15637.21 |
| 16K | 3648 | 4 | 16561.26 | 16339.42 | 16099.24 | 15871.28 | 15637.21 |
| 16K | 4096 | 3 | 16020.04 | 15805.70 | 15573.04 | 15352.59 | 15126.04 |
| 32K | 192 | 32 | 32097.48 | 31668.05 | 31201.95 | 30760.29 | 30306.41 |
| 32K | 384 | 32 | 32097.48 | 31668.05 | 31201.95 | 30760.29 | 30306.41 |
| 32K | 512 | 24 | 32475.84 | 32041.14 | 31569.77 | 31122.85 | 30663.71 |
| 32K | 768 | 16 | 32951.95 | 32510.63 | 32032.64 | 31579.09 | 31113.33 |
| 32K | 1024 | 12 | 33165.03 | 32720.74 | 32239.78 | 31783.27 | 31314.54 |
| 32K | 1536 | 8 | 34048.92 | 33592.35 | 33099.12 | 32630.32 | 32149.31 |
| 32K | 2048 | 6 | 33842.90 | 33389.18 | 32898.80 | 32432.87 | 31954.71 |
| 32K | 2432 | 6 | 33842.90 | 33389.18 | 32898.80 | 32432.87 | 31954.71 |
| 32K | 3072 | 8 | 34048.92 | 33592.35 | 33099.12 | 32630.32 | 32149.31 |
| 32K | 3072 | 3 | 32038.72 | 31610.06 | 31144.72 | 30703.83 | 30250.72 |
| 32K | 3648 | 8 | 34048.92 | 33592.35 | 33099.12 | 32630.32 | 32149.31 |
| 32K | 3648 | 3 | 32038.72 | 31610.06 | 31144.72 | 30703.83 | 30250.72 |
| 32K | 4096 | 3 | 32038.72 | 31610.06 | 31144.72 | 30703.83 | 30250.72 |
| 32K | 4864 | 3 | 32038.72 | 31610.06 | 31144.72 | 30703.83 | 30250.72 |

## I.2 DATA AND SUBFRAME BOUNDARY SYMBOL FREQUENCY DOMAIN POWER

The following tables describe the total frequency domain power in data and subframe boundary symbols. Table entries shown in brackets and italicized are for FFT size and scattered pilot pattern combinations that are not allowed (refer to Table 8.3).

**Table I.2.1** Frequency Domain Total Power of Each Data and Subframe Boundary Symbol ($P_{\text{data,m}}$) when $C_{red_coeff}$=0

| FFT Size | Pilot Pattern | L1D_scattered_pilot_boost | | | | |
|---|---|---|---|---|---|---|
| | | 000 | 001 | 010 | 011 | 100 |
| 8K | SP3_2 | 7206.33 | 7206.33 | 7646.12 | 7967.68 | 8302.73 |
| | SP3_4 | 7206.33 | 7427.12 | 7757.73 | 8018.64 | 8223.83 |
| | SP4_2 | 7206.33 | 7335.49 | 7745.44 | 8069.14 | 8324.24 |
| | SP4_4 | 7206.33 | 7477.44 | 7769.24 | 7971.39 | 8181.27 |
| | SP6_2 | 7206.33 | 7463.93 | 7809.46 | 8080.54 | 8295.62 |
| | SP6_4 | 7206.33 | 7497.87 | 7737.93 | 7927.21 | 8077.51 |
| | SP8_2 | 7206.33 | 7492.88 | 7814.32 | 8024.02 | 8243.34 |
| | SP8_4 | 7206.33 | 7490.93 | 7698.42 | 7862.96 | 7992.15 |
| | SP12_2 | 7206.33 | 7522.86 | 7773.18 | 7969.29 | 8125.67 |
| | SP12_4 | 7206.33 | 7475.54 | 7648.41 | 7783.36 | 7891.04 |
| | SP16_2 | 7206.33 | 7512.03 | 7727.53 | 7897.38 | 8031.80 |
| | SP16_4 | 7206.33 | 7466.13 | 7618.63 | 7738.99 | 7835.14 |
| | SP24_2 | 7206.33 | 7491.23 | 7669.09 | 7809.50 | 7920.09 |
| | SP24_4 | 7206.33 | 7440.66 | 7568.35 | 7669.30 | 7748.41 |
| | SP32_2 | 7206.33 | 7477.75 | 7635.15 | 7744.12 | 7857.61 |
| | SP32_4 | 7206.33 | 7420.32 | 7532.04 | 7620.18 | 7690.50 |
| 16K | SP3_2 | 14411.67 | 14411.67 | 15288.86 | 15932.70 | 16602.50 |
| | SP3_4 | 14411.67 | 14851.86 | 15510.50 | 16028.89 | 16439.91 |
| | SP4_2 | 14411.67 | 14668.83 | 15488.26 | 16134.29 | 16645.20 |
| | SP4_4 | 14411.67 | 14952.26 | 15532.20 | 15935.04 | 16353.30 |
| | SP6_2 | 14411.67 | 14926.41 | 15613.87 | 16156.56 | 16586.36 |
| | SP6_4 | 14411.67 | 14989.75 | 15467.04 | 15842.95 | 16141.04 |
| | SP8_2 | 14411.67 | 14983.09 | 15623.25 | 16044.16 | 16480.28 |
| | SP8_4 | 14411.67 | 14974.58 | 15386.60 | 15711.94 | 15968.72 |
| | SP12_2 | 14411.67 | 15041.63 | 15540.41 | 15932.96 | 16244.17 |
| | SP12_4 | 14411.67 | 14943.26 | 15282.84 | 15550.82 | 15762.46 |
| | SP16_2 | 14411.67 | 15019.66 | 15448.67 | 15787.59 | 16055.82 |
| | SP16_4 | 14411.67 | 14920.95 | 15221.58 | 15458.22 | 15645.66 |
| | SP24_2 | 14411.67 | 14978.51 | 15331.00 | 15609.88 | 15830.29 |
| | SP24_4 | 14411.67 | 14867.25 | 15115.96 | 15311.51 | 15466.70 |
| | SP32_2 | 14411.67 | 14950.04 | 15261.41 | 15477.36 | 15702.29 |
| | SP32_4 | 14411.67 | 14823.96 | 15040.47 | 15210.22 | 15345.66 |
| 32K | SP3_2 | 28822.33 | 28822.33 | 30576.34 | 31863.75 | 33202.05 |
| | SP3_4 | *(28822.33)* | *(29700.34)* | *(31015.05)* | *(32051.38)* | *(32872.06)* |
| | SP4_2 | *N/A* | *N/A* | *N/A* | *N/A* | *N/A* |
| | SP4_4 | *N/A* | *N/A* | *N/A* | *N/A* | *N/A* |
| | SP6_2 | 28822.33 | 29850.37 | 31224.70 | 32309.62 | 33167.83 |
| | SP6_4 | *(28822.33)* | *(29973.50)* | *(30925.26)* | *(31675.43)* | *(32269.09)* |

| | | | | | | |
|---|---|---|---|---|---|---|
| | SP8_2 | 28822.33 | 29963.53 | 31243.10 | 32082.43 | 32955.18 |
| | SP8_4 | *(28822.33)* | *(29942.86)* | *(30763.97)* | *(31410.90)* | *(31921.87)* |
| | SP12_2 | 28822.33 | 30080.16 | 31074.87 | 31858.28 | 32479.17 |
| | SP12_4 | *(28822.33)* | *(29877.71)* | *(30551.70)* | *(31083.74)* | *(31504.30)* |
| | SP16_2 | 28822.33 | 30033.92 | 30890.95 | 31567.00 | 32101.85 |
| | SP16_4 | *(28822.33)* | *(29830.59)* | *(30426.47)* | *(30895.69)* | *(31267.72)* |
| | SP24_2 | 28822.33 | 29951.08 | 30654.84 | 31209.63 | 31648.70 |
| | SP24_4 | *(28822.33)* | *(29720.43)* | *(30211.16)* | *(30597.95)* | *(30904.27)* |
| | SP32_2 | 28822.33 | 29893.61 | 30514.92 | 30944.83 | 31391.67 |
| | SP32_4 | *(28822.33)* | *(29632.24)* | *(30056.33)* | *(30391.32)* | *(30655.98)* |

**Table I.2.2** Frequency Domain Total Power of Each Data and Subframe Boundary Symbol ($P_{\text{data,m}}$) when $C_{red_coeff}$=1

| **FFT Size** | **Pilot Pattern** | **L1D_scattered_pilot_boost** | | | | |
|---|---|---|---|---|---|---|
| | | **000** | **001** | **010** | **011** | **100** |
| **8K** | SP3_2 | 7110.33 | 7110.33 | 7543.95 | 7861.57 | 8191.33 |
| | SP3_4 | 7110.33 | 7327.95 | 7654.33 | 7910.88 | 8114.70 |
| | SP4_2 | 7110.33 | 7236.94 | 7641.52 | 7961.26 | 8213.26 |
| | SP4_4 | 7110.33 | 7378.52 | 7666.26 | 7865.29 | 8072.61 |
| | SP6_2 | 7110.33 | 7364.80 | 7704.79 | 7972.35 | 8184.48 |
| | SP6_4 | 7110.33 | 7397.95 | 7634.83 | 7821.73 | 7969.81 |
| | SP8_2 | 7110.33 | 7392.96 | 7709.54 | 7917.41 | 8132.67 |
| | SP8_4 | 7110.33 | 7391.44 | 7595.59 | 7758.19 | 7885.30 |
| | SP12_2 | 7110.33 | 7422.14 | 7668.57 | 7863.25 | 8017.32 |
| | SP12_4 | 7110.33 | 7375.99 | 7546.56 | 7680.17 | 7786.06 |
| | SP16_2 | 7110.33 | 7411.63 | 7624.20 | 7792.37 | 7925.08 |
| | SP16_4 | 7110.33 | 7363.26 | 7511.56 | 7629.46 | 7721.49 |
| | SP24_2 | 7110.33 | 7391.43 | 7567.41 | 7704.99 | 7814.54 |
| | SP24_4 | 7110.33 | 7341.37 | 7467.34 | 7566.98 | 7645.90 |
| | SP32_2 | 7110.33 | 7377.35 | 7531.46 | 7638.46 | 7749.85 |
| | SP32_4 | 7110.33 | 7313.29 | 7419.22 | 7502.79 | 7569.50 |
| **16K** | SP3_2 | 14219.67 | 14219.67 | 15085.51 | 15720.49 | 16379.71 |
| | SP3_4 | 14219.67 | 14653.51 | 15302.71 | 15814.36 | 16219.64 |
| | SP4_2 | 14219.67 | 14472.72 | 15281.42 | 15918.52 | 16422.23 |
| | SP4_4 | 14219.67 | 14752.42 | 15325.23 | 15721.83 | 16133.97 |
| | SP6_2 | 14219.67 | 14727.15 | 15405.54 | 15941.18 | 16364.07 |
| | SP6_4 | 14219.67 | 14789.90 | 15259.85 | 15632.00 | 15925.64 |
| | SP8_2 | 14219.67 | 14783.26 | 15414.68 | 15828.94 | 16259.96 |
| | SP8_4 | 14219.67 | 14775.60 | 15181.94 | 15502.39 | 15756.02 |
| | SP12_2 | 14219.67 | 14841.20 | 15332.19 | 15719.86 | 16026.47 |
| | SP12_4 | 14219.67 | 14744.17 | 15079.15 | 15342.45 | 15551.49 |
| | SP16_2 | 14219.67 | 14818.87 | 15242.01 | 15576.56 | 15840.38 |
| | SP16_4 | 14219.67 | 14722.22 | 15018.45 | 15252.17 | 15436.38 |
| | SP24_2 | 14219.67 | 14777.90 | 15126.65 | 15400.85 | 15618.19 |
| | SP24_4 | 14219.67 | 14668.66 | 14913.92 | 15107.88 | 15260.67 |
| | SP32_2 | 14219.67 | 14750.23 | 15058.02 | 15271.03 | 15492.78 |
| | SP32_4 | 14219.67 | 14620.90 | 14830.83 | 14997.45 | 15128.66 |

| | | | | | | |
|---|---|---|---|---|---|---|
| **32K** | SP3_2 | 28438.33 | 28438.33 | 30167.65 | 31437.32 | 32756.47 |
| | SP3_4 | *(28438.33)* | *(29304.65)* | *(30600.47)* | *(31622.33)* | *(32431.52)* |
| | SP4_2 | *N/A* | *N/A* | *N/A* | *N/A* | *N/A* |
| | SP4_4 | *N/A* | *N/A* | *N/A* | *N/A* | *N/A* |
| | SP6_2 | 28438.33 | 29451.86 | 30808.03 | 31876.86 | 32723.26 |
| | SP6_4 | *(28438.33)* | *(29573.80)* | *(30511.88)* | *(31251.52)* | *(31837.30)* |
| | SP8_2 | 28438.33 | 29563.87 | 30824.95 | 31653.00 | 32513.53 |
| | SP8_4 | *(28438.33)* | *(29543.90)* | *(30352.64)* | *(30990.81)* | *(31495.47)* |
| | SP12_2 | 28438.33 | 29678.30 | 30659.43 | 31433.10 | 32044.77 |
| | SP12_4 | *(28438.33)* | *(29478.52)* | *(30144.31)* | *(30668.01)* | *(31083.35)* |
| | SP16_2 | 28438.33 | 29633.34 | 30478.63 | 31144.96 | 31671.98 |
| | SP16_4 | *(28438.33)* | *(29433.12)* | *(30020.22)* | *(30483.58)* | *(30850.16)* |
| | SP24_2 | 28438.33 | 29550.86 | 30245.14 | 30792.57 | 31225.49 |
| | SP24_4 | *(28438.33)* | *(29324.25)* | *(29808.09)* | *(30189.68)* | *(30492.22)* |
| | SP32_2 | 28438.33 | 29495.00 | 30107.15 | 30531.17 | 30971.65 |
| | SP32_4 | *(28438.33)* | *(29237.11)* | *(29655.05)* | *(29985.78)* | *(30246.99)* |

**Table I.2.3** Frequency Domain Total Power of Each Data and Subframe Boundary Symbol ($P_{\text{data,m}}$) when $C_{red_coeff}$=2

| **FFTSize** | **Pilot Pattern** | **L1D_scattered_pilot_boost** | | | | |
|---|---|---|---|---|---|---|
| | | **000** | **001** | **010** | **011** | **100** |
| **8K** | SP3_2 | 7008.22 | 7008.22 | 7435.66 | 7748.36 | 8074.82 |
| | SP3_4 | 7008.22 | 7223.66 | 7544.82 | 7798.01 | 7998.45 |
| | SP4_2 | 7008.22 | 7133.27 | 7532.48 | 7846.26 | 8095.17 |
| | SP4_4 | 7008.22 | 7272.48 | 7556.17 | 7752.08 | 7956.83 |
| | SP6_2 | 7008.22 | 7258.56 | 7594.01 | 7858.05 | 8067.22 |
| | SP6_4 | 7008.22 | 7290.91 | 7525.63 | 7709.14 | 7855.00 |
| | SP8_2 | 7008.22 | 7286.93 | 7598.64 | 7803.69 | 8016.90 |
| | SP8_4 | 7008.22 | 7284.84 | 7487.64 | 7646.30 | 7773.33 |
| | SP12_2 | 7008.22 | 7316.32 | 7558.85 | 7751.09 | 7901.86 |
| | SP12_4 | 7008.22 | 7270.34 | 7437.60 | 7569.88 | 7674.96 |
| | SP16_2 | 7008.22 | 7305.13 | 7514.76 | 7680.24 | 7811.25 |
| | SP16_4 | 7008.22 | 7260.28 | 7409.39 | 7526.82 | 7619.74 |
| | SP24_2 | 7008.22 | 7285.51 | 7458.63 | 7595.36 | 7702.87 |
| | SP24_4 | 7008.22 | 7235.96 | 7360.21 | 7458.55 | 7536.28 |
| | SP32_2 | 7008.22 | 7272.84 | 7425.66 | 7531.68 | 7641.99 |
| | SP32_4 | 7008.22 | 7211.14 | 7317.29 | 7400.29 | 7467.39 |
| **16K** | SP3_2 | 14009.33 | 14009.33 | 14862.84 | 15488.94 | 16139.59 |
| | SP3_4 | 14009.33 | 14437.84 | 15077.59 | 15582.50 | 15982.03 |
| | SP4_2 | 14009.33 | 14259.28 | 15055.24 | 15683.41 | 16180.94 |
| | SP4_4 | 14009.33 | 14534.24 | 15098.94 | 15490.30 | 15897.32 |
| | SP6_2 | 14009.33 | 14509.56 | 15178.87 | 15706.47 | 16123.45 |
| | SP6_4 | 14009.33 | 14570.72 | 15035.33 | 15401.71 | 15690.92 |
| | SP8_2 | 14009.33 | 14565.10 | 15187.77 | 15596.39 | 16021.30 |
| | SP8_4 | 14009.33 | 14557.28 | 14957.94 | 15273.51 | 15523.99 |
| | SP12_2 | 14009.33 | 14622.43 | 15106.64 | 15488.44 | 15790.44 |
| | SP12_4 | 14009.33 | 14526.74 | 14856.11 | 15116.75 | 15323.18 |

| | | | | | | |
|---|---|---|---|---|---|---|
| | SP16_2 | 14009.33 | 14599.75 | 15018.01 | 15347.20 | 15607.61 |
| | SP16_4 | 14009.33 | 14504.15 | 14796.99 | 15026.78 | 15209.77 |
| | SP24_2 | 14009.33 | 14559.96 | 14902.97 | 15174.49 | 15388.75 |
| | SP24_4 | 14009.33 | 14452.74 | 14694.55 | 14884.91 | 15036.31 |
| | SP32_2 | 14009.33 | 14533.10 | 14836.30 | 15046.37 | 15264.94 |
| | SP32_4 | 14009.33 | 14410.50 | 14620.85 | 14786.35 | 14918.33 |
| **32K** | SP3_2 | 28017.67 | 28017.67 | 29723.29 | 30974.22 | 32275.22 |
| | SP3_4 | *(28017.67)* | *(28871.29)* | *(30149.22)* | *(31157.61)* | *(31954.31)* |
| | SP4_2 | *N/A* | *N/A* | *N/A* | *N/A* | *N/A* |
| | SP4_4 | *N/A* | *N/A* | *N/A* | *N/A* | *N/A* |
| | SP6_2 | 28017.67 | 29016.68 | 30353.69 | 31407.43 | 32242.01 |
| | SP6_4 | *(28017.67)* | *(29136.44)* | *(30061.84)* | *(30791.94)* | *(31368.85)* |
| | SP8_2 | 28017.67 | 29127.54 | 30371.14 | 31186.90 | 32035.22 |
| | SP8_4 | *(28017.67)* | *(29107.27)* | *(29905.65)* | *(30534.05)* | *(31032.40)* |
| | SP12_2 | 28017.67 | 29240.78 | 30207.33 | 30970.25 | 31573.71 |
| | SP12_4 | *(28017.67)* | *(29043.66)* | *(29699.25)* | *(30216.61)* | *(30625.74)* |
| | SP16_2 | 28017.67 | 29196.10 | 30029.64 | 30686.24 | 31206.44 |
| | SP16_4 | *(28017.67)* | *(28997.98)* | *(29577.29)* | *(30033.81)* | *(30395.92)* |
| | SP24_2 | 28017.67 | 29114.97 | 29798.77 | 30338.84 | 30765.60 |
| | SP24_4 | *(28017.67)* | *(28891.40)* | *(29368.35)* | *(29744.74)* | *(30042.50)* |
| | SP32_2 | 28017.67 | 29059.72 | 29662.71 | 30080.84 | 30515.97 |
| | SP32_4 | *(28017.67)* | *(28805.32)* | *(29218.10)* | *(29543.57)* | *(29801.34)* |

**Table I.2.4** Frequency Domain Total Power of Each Data and Subframe Boundary Symbol ($P_{\text{data,m}}$) when $C_{red_coeff}$=3

| **FFT Size** | **Pilot Pattern** | **L1D_scattered_pilot_boost** | | | | |
|---|---|---|---|---|---|---|
| | | **000** | **001** | **010** | **011** | **100** |
| **8K** | SP3_2 | 6906.11 | 6906.11 | 7327.38 | 7636.14 | 7957.32 |
| | SP3_4 | 6906.11 | 7118.38 | 7434.32 | 7684.13 | 7882.20 |
| | SP4_2 | 6906.11 | 7029.60 | 7422.45 | 7732.26 | 7978.08 |
| | SP4_4 | 6906.11 | 7166.45 | 7446.08 | 7639.87 | 7841.06 |
| | SP6_2 | 6906.11 | 7153.32 | 7484.23 | 7743.75 | 7949.97 |
| | SP6_4 | 6906.11 | 7184.88 | 7415.42 | 7597.55 | 7741.20 |
| | SP8_2 | 6906.11 | 7180.91 | 7488.74 | 7689.97 | 7900.13 |
| | SP8_4 | 6906.11 | 7179.24 | 7378.70 | 7535.42 | 7660.37 |
| | SP12_2 | 6906.11 | 7209.49 | 7449.13 | 7637.93 | 7787.40 |
| | SP12_4 | 6906.11 | 7164.68 | 7329.64 | 7460.59 | 7562.86 |
| | SP16_2 | 6906.11 | 7198.63 | 7405.31 | 7569.12 | 7698.43 |
| | SP16_4 | 6906.11 | 7151.31 | 7296.21 | 7410.19 | 7500.99 |
| | SP24_2 | 6906.11 | 7179.60 | 7349.84 | 7484.74 | 7591.21 |
| | SP24_4 | 6906.11 | 7130.55 | 7254.08 | 7350.12 | 7426.65 |
| | SP32_2 | 6906.11 | 7165.32 | 7315.85 | 7419.91 | 7528.12 |
| | SP32_4 | 6906.11 | 7109.00 | 7215.35 | 7298.80 | 7365.28 |
| **16K** | SP3_2 | 13811.22 | 13811.22 | 14652.38 | 15269.62 | 15910.69 |
| | SP3_4 | 13811.22 | 14233.38 | 14863.69 | 15361.87 | 15755.65 |
| | SP4_2 | 13811.22 | 14057.06 | 14842.28 | 15461.53 | 15951.87 |
| | SP4_4 | 13811.22 | 14329.28 | 14885.87 | 15270.98 | 15671.88 |

| | | | | | | |
|---|---|---|---|---|---|---|
| | SP6_2 | 13811.22 | 14304.20 | 14963.42 | 15483.98 | 15895.05 |
| | SP6_4 | 13811.22 | 14364.76 | 14823.03 | 15183.64 | 15469.41 |
| | SP8_2 | 13811.22 | 14359.16 | 14973.09 | 15375.06 | 15793.87 |
| | SP8_4 | 13811.22 | 14351.19 | 14746.17 | 15057.86 | 15304.17 |
| | SP12_2 | 13811.22 | 14414.89 | 14892.31 | 15269.23 | 15567.63 |
| | SP12_4 | 13811.22 | 14320.54 | 14646.31 | 14903.28 | 15106.09 |
| | SP16_2 | 13811.22 | 14393.85 | 14805.24 | 15130.07 | 15387.07 |
| | SP16_4 | 13811.22 | 14299.30 | 14587.75 | 14814.62 | 14994.37 |
| | SP24_2 | 13811.22 | 14354.24 | 14692.51 | 14959.35 | 15170.53 |
| | SP24_4 | 13811.22 | 14248.04 | 14486.41 | 14675.16 | 14824.17 |
| | SP32_2 | 13811.22 | 14327.18 | 14626.80 | 14832.92 | 15048.32 |
| | SP32_4 | 13811.22 | 14201.32 | 14406.10 | 14567.47 | 14695.23 |
| **32K** | SP3_2 | 27621.44 | 27621.44 | 29302.38 | 30535.58 | 31818.42 |
| | SP3_4 | *(27621.44)* | *(28463.38)* | *(29723.42)* | *(30716.34)* | *(31502.55)* |
| | SP4_2 | *N/A* | *N/A* | *N/A* | *N/A* | *N/A* |
| | SP4_4 | *N/A* | *N/A* | *N/A* | *N/A* | *N/A* |
| | SP6_2 | 27621.44 | 28605.95 | 29923.80 | 30963.45 | 31785.21 |
| | SP6_4 | *(27621.44)* | *(28724.52)* | *(29636.24)* | *(30355.81)* | *(30924.84)* |
| | SP8_2 | 27621.44 | 28715.66 | 29940.78 | 30745.24 | 31582.35 |
| | SP8_4 | *(27621.44)* | *(28696.09)* | *(29482.10)* | *(30101.74)* | *(30592.78)* |
| | SP12_2 | 27621.44 | 28826.70 | 29779.67 | 30531.84 | 31126.09 |
| | SP12_4 | *(27621.44)* | *(28633.25)* | *(29279.63)* | *(29788.66)* | *(30192.56)* |
| | SP16_2 | 27621.44 | 28783.31 | 29604.09 | 30251.97 | 30764.35 |
| | SP16_4 | *(27621.44)* | *(28588.29)* | *(29158.82)* | *(29609.48)* | *(29966.13)* |
| | SP24_2 | 27621.44 | 28702.53 | 29377.85 | 29909.56 | 30330.17 |
| | SP24_4 | *(27621.44)* | *(28483.00)* | *(28953.06)* | *(29324.25)* | *(29618.22)* |
| | SP32_2 | 27621.44 | 28647.89 | 29243.71 | 29655.96 | 30083.72 |
| | SP32_4 | *(27621.44)* | *(28397.97)* | *(28804.59)* | *(29125.81)* | *(29380.12)* |

**Table I.2.5** Frequency Domain Total Power of Each Data and Subframe Boundary Symbol ($P_{\text{data,m}}$) when $C_{red_coeff}$=4

| **FFT Size** | **Pilot Pattern** | **L1D_scattered_pilot_boost** | | | | |
|---|---|---|---|---|---|---|
| | | **000** | **001** | **010** | **011** | **100** |
| **8K** | SP3_2 | 6804.00 | 6804.00 | 7219.10 | 7523.92 | 7839.81 |
| | SP3_4 | 6804.00 | 7013.10 | 7324.81 | 7571.26 | 7765.96 |
| | SP4_2 | 6804.00 | 6925.93 | 7313.42 | 7618.26 | 7859.99 |
| | SP4_4 | 6804.00 | 7060.42 | 7335.99 | 7527.66 | 7725.28 |
| | SP6_2 | 6804.00 | 7048.08 | 7373.45 | 7630.44 | 7832.71 |
| | SP6_4 | 6804.00 | 7078.84 | 7306.22 | 7485.96 | 7627.39 |
| | SP8_2 | 6804.00 | 7074.88 | 7377.85 | 7577.25 | 7783.36 |
| | SP8_4 | 6804.00 | 7072.64 | 7269.76 | 7424.54 | 7547.41 |
| | SP12_2 | 6804.00 | 7102.67 | 7339.41 | 7525.78 | 7672.94 |
| | SP12_4 | 6804.00 | 7059.02 | 7221.68 | 7350.29 | 7451.76 |
| | SP16_2 | 6804.00 | 7093.12 | 7296.87 | 7457.00 | 7584.60 |
| | SP16_4 | 6804.00 | 7049.33 | 7194.04 | 7308.55 | 7399.24 |
| | SP24_2 | 6804.00 | 7073.68 | 7242.05 | 7374.11 | 7479.54 |
| | SP24_4 | 6804.00 | 7026.15 | 7146.95 | 7242.69 | 7318.03 |

| | | | | | | |
|---|---|---|---|---|---|---|
| | SP32_2 | 6804.00 | 7060.81 | 7210.05 | 7313.13 | 7420.25 |
| | SP32_4 | 6804.00 | 7006.86 | 7112.42 | 7196.30 | 7263.17 |
| **16K** | SP3_2 | 13607.00 | 13607.00 | 14435.81 | 15044.18 | 15676.67 |
| | SP3_4 | 13607.00 | 14022.81 | 14644.67 | 15135.12 | 15523.16 |
| | SP4_2 | 13607.00 | 13849.72 | 14623.21 | 15233.53 | 15716.68 |
| | SP4_4 | 13607.00 | 14117.21 | 14665.68 | 15045.56 | 15441.33 |
| | SP6_2 | 13607.00 | 14092.72 | 14742.86 | 15255.38 | 15661.54 |
| | SP6_4 | 13607.00 | 14152.69 | 14603.62 | 14959.46 | 15240.79 |
| | SP8_2 | 13607.00 | 14147.11 | 14751.29 | 15148.62 | 15561.33 |
| | SP8_4 | 13607.00 | 14138.99 | 14528.28 | 14836.09 | 15078.25 |
| | SP12_2 | 13607.00 | 14202.24 | 14672.87 | 15043.92 | 15337.71 |
| | SP12_4 | 13607.00 | 14109.22 | 14430.39 | 14683.69 | 14883.90 |
| | SP16_2 | 13607.00 | 14180.85 | 14586.36 | 14906.82 | 15159.41 |
| | SP16_4 | 13607.00 | 14088.34 | 14372.40 | 14596.34 | 14773.87 |
| | SP24_2 | 13607.00 | 14142.41 | 14475.94 | 14739.09 | 14947.20 |
| | SP24_4 | 13607.00 | 14038.22 | 14273.15 | 14458.30 | 14605.93 |
| | SP32_2 | 13607.00 | 14116.15 | 14410.20 | 14614.37 | 14826.59 |
| | SP32_4 | 13607.00 | 13997.04 | 14202.24 | 14363.48 | 14491.01 |
| **32K** | SP3_2 | 27213.00 | 27213.00 | 28869.25 | 30085.70 | 31349.40 |
| | SP3_4 | *(27213.00)* | *(28042.25)* | *(29284.40)* | *(30262.84)* | *(31037.56)* |
| | SP4_2 | *N/A* | *N/A* | *N/A* | *N/A* | *N/A* |
| | SP4_4 | *N/A* | *N/A* | *N/A* | *N/A* | *N/A* |
| | SP6_2 | 27213.00 | 28184.00 | 29482.69 | 30506.24 | 31317.19 |
| | SP6_4 | *(27213.00)* | *(28300.38)* | *(29199.42)* | *(29907.46)* | *(30468.61)* |
| | SP8_2 | 27213.00 | 28291.55 | 29499.19 | 30292.36 | 31116.26 |
| | SP8_4 | *(27213.00)* | *(28271.68)* | *(29047.33)* | *(29658.20)* | *(30141.93)* |
| | SP12_2 | 27213.00 | 28400.40 | 29340.78 | 30081.21 | 30667.25 |
| | SP12_4 | *(27213.00)* | *(28209.62)* | *(28846.79)* | *(29349.48)* | *(29747.17)* |
| | SP16_2 | 27213.00 | 28357.29 | 29167.33 | 29805.48 | 30311.03 |
| | SP16_4 | *(27213.00)* | *(28165.37)* | *(28728.11)* | *(29171.93)* | *(29523.12)* |
| | SP24_2 | 27213.00 | 28278.87 | 28943.71 | 29468.06 | 29882.51 |
| | SP24_4 | *(27213.00)* | *(28061.37)* | *(28525.54)* | *(28891.53)* | *(29180.72)* |
| | SP32_2 | 27213.00 | 28224.84 | 28811.49 | 29217.85 | 29640.26 |
| | SP32_4 | *(27213.00)* | *(27978.40)* | *(28379.87)* | *(28695.83)* | *(28946.69)* |

# *Annex J*: MISO

## J.1 MISO FREQUENCY DOMAIN COEFFICIENTS

**Table J.1.1** Time Domain Impulse Response Vectors for $N_{MISO}$=64

| n | $N_{TX}$=2 | | $N_{TX}$=3 | | | $N_{TX}$=4 | | | |
|---|---|---|---|---|---|---|---|---|---|
| | h1 | h2 | h1 | h2 | h3 | h1 | h2 | h3 | h4 |
| 0 | -0.0082-j0.0031 | 0.0570+j0.0402 | -0.0202-j0.0157 | -0.0351-j0.0356 | 0.0436+j0.0054 | 0.0240-j0.0409 | -0.0263-j0.0479 | -0.0233-j0.0047 | 0.0050+j0.0373 |
| 1 | 0.0041-j0.0092 | -0.0200+j0.0170 | -0.0397-j0.0295 | 0.0087-j0.0039 | 0.0171-j0.0086 | 0.0012-j0.0723 | -0.0301-j0.0107 | 0.0235+j0.0189 | 0.0239+j0.0232 |
| 2 | -0.0192-j0.0795 | -0.0538+j0.0115 | 0.0051-j0.0108 | -0.0400-j0.0028 | -0.0079-j0.0112 | -0.0192-j0.0187 | 0.0333-j0.0063 | 0.0180+j0.0330 | 0.0302-j0.0206 |
| 3 | -0.0321+j0.0025 | -0.0197-j0.1022 | 0.0365-j0.0003 | 0.0228+j0.0060 | 0.0037-j0.0093 | 0.0487+j0.0256 | 0.0204+j0.0289 | -0.0042-j0.0688 | -0.0148-j0.0121 |
| 4 | -0.0234+j0.0615 | -0.0244-j0.0409 | -0.0195-j0.0111 | 0.0347-j0.0134 | 0.0549-j0.0019 | 0.0508-j0.0429 | -0.0105+j0.0583 | 0.0140-j0.0162 | -0.0007-j0.0009 |
| 5 | -0.0257-j0.0544 | 0.0925+j0.0289 | -0.1033+j0.0267 | -0.0351-j0.0292 | -0.0391+j0.0219 | -0.0400-j0.0598 | -0.0649-j0.1346 | -0.0297+j0.0627 | -0.0177-j0.0167 |
| 6 | -0.0599-j0.0362 | -0.0082+j0.0075 | -0.0409+j0.0354 | -0.0091-j0.0239 | -0.0306-j0.0150 | -0.0299+j0.0292 | -0.0243-j0.0626 | -0.0144-j0.0526 | -0.0166+j0.0221 |
| 7 | -0.0472+j0.0203 | 0.0795+j0.0501 | -0.0243-j0.0359 | -0.1048-j0.0459 | 0.0398+j0.0042 | 0.0171-j0.0085 | 0.0599-j0.0728 | -0.0466+j0.0299 | -0.0181-j0.0276 |
| 8 | 0.0925-j0.0460 | 0.0124-j0.0371 | -0.0291-j0.0020 | 0.0814-j0.0157 | -0.0360+j0.0737 | -0.0452-j0.0488 | 0.0119+j0.0809 | 0.0060+j0.0085 | 0.0012+j0.0362 |
| 9 | 0.0217-j0.0165 | 0.0266+j0.0384 | 0.0027+j0.1260 | 0.0278+j0.0517 | 0.0432-j0.0191 | -0.1012+j0.0784 | 0.0566+j0.0771 | 0.0173+j0.1123 | 0.0114+j0.0245 |
| 10 | -0.1060+j0.0672 | -0.0644-j0.0655 | 0.0495+j0.0905 | -0.0310+j0.0042 | -0.0297-j0.0303 | 0.0182+j0.0737 | -0.0317-j0.1009 | -0.0095-j0.0079 | -0.0201+j0.0881 |
| 11 | 0.0356+j0.0135 | -0.0565+j0.0211 | 0.0206-j0.0591 | 0.0082-j0.0551 | -0.0421-j0.0442 | 0.0460-j0.0497 | 0.0592+j0.0811 | 0.0554+j0.0071 | 0.0430+j0.0391 |
| 12 | -0.0765-j0.0388 | 0.0711+j0.0100 | -0.0658+j0.0847 | -0.1074-j0.1147 | -0.0423+j0.0888 | -0.1181+j0.0534 | -0.1045-j0.1392 | 0.0341-j0.0753 | 0.0106-j0.0458 |
| 13 | -0.1158+j0.1144 | -0.0186+j0.0228 | 0.0361+j0.0878 | 0.0709+j0.0104 | 0.0681-j0.0220 | -0.0447+j0.1291 | -0.1084+j0.0149 | -0.0615+j0.0015 | -0.0337-j0.0743 |
| 14 | 0.0197+j0.1516 | 0.1920-j0.0084 | 0.1156-j0.0646 | 0.0134-j0.0183 | -0.1486-j0.0084 | 0.1023-j0.0167 | 0.0758-j0.0852 | -0.1283+j0.0457 | -0.0617+j0.0517 |
| 15 | -0.0359+j0.0376 | 0.0029-j0.0932 | -0.1034-j0.0663 | 0.0391+j0.0550 | 0.1086-j0.0260 | -0.0501-j0.1357 | 0.0799-j0.0393 | 0.0546-j0.1677 | 0.0011+j0.0323 |
| 16 | -0.0932+j0.0818 | 0.1438+j0.0361 | -0.1042-j0.0011 | 0.2130+j0.1695 | -0.0102+j0.0763 | -0.0843-j0.1035 | 0.2092+j0.1991 | -0.0932+j0.2335 | -0.0128+j0.0034 |
| 17 | -0.0454+j0.1093 | -0.0405+j0.0996 | 0.0373+j0.0515 | -0.2063+j0.0635 | -0.0520-j0.0592 | -0.0382-j0.0540 | -0.1139-j0.0389 | -0.1123+j0.0290 | -0.0525-j0.0809 |
| 18 | 0.0692-j0.0114 | -0.1229+j0.1549 | -0.1169-j0.0665 | -0.0821+j0.0257 | 0.0022-j0.0342 | -0.0657-j0.1025 | -0.0529-j0.0304 | 0.1421+j0.0877 | -0.0457+j0.1235 |
| 19 | -0.0801-j0.0271 | -0.0177-j0.1009 | -0.1598-j0.0456 | -0.1664-j0.1884 | -0.0331+j0.0601 | -0.0362-j0.0847 | -0.0902-j0.1026 | 0.0467-j0.1229 | 0.1259+j0.0362 |
| 20 | -0.1156-j0.0505 | 0.0610-j0.0604 | 0.0191-j0.0271 | 0.0600+j0.0789 | -0.0826+j0.0136 | 0.0219-j0.0437 | 0.0859+j0.0258 | 0.0059+j0.0987 | -0.0608-j0.0147 |
| 21 | 0.2071-j0.0987 | 0.3258-j0.0067 | 0.0155-j0.0469 | 0.1633+j0.1717 | 0.1155+j0.2692 | 0.0146-j0.0333 | 0.1311+j0.1771 | 0.0374-j0.0089 | -0.0241-j0.2151 |
| 22 | 0.0217+j0.1298 | 0.0486+j0.1430 | -0.0536+j0.1606 | -0.1040+j0.1295 | 0.0776-j0.2126 | -0.1189+j0.1498 | 0.0212+j0.0289 | -0.0469-j0.1116 | -0.2348+j0.0577 |
| 23 | 0.0305+j0.1189 | 0.0057+j0.0169 | -0.0881+j0.1063 | 0.1314-j0.0204 | 0.0330-j0.0684 | -0.1678+j0.0733 | 0.1347-j0.0075 | -0.0315+j0.0372 | 0.0898+j0.0509 |
| 24 | 0.1325+j0.1816 | -0.0468+j0.0400 | 0.0136+j0.1160 | -0.1336+j0.0564 | 0.0150-j0.0269 | -0.0205+j0.0349 | -0.0492+j0.1194 | -0.0329+j0.0249 | 0.0000-j0.0149 |
| 25 | 0.0220+j0.1673 | -0.0580+j0.1502 | -0.0165+j0.0980 | -0.0383+j0.1788 | -0.1286+j0.0254 | -0.0220+j0.1345 | -0.0598+j0.0809 | -0.1220+j0.1634 | -0.1193+j0.0479 |
| 26 | 0.2034-j0.1647 | 0.0839+j0.2601 | 0.3054-j0.0506 | -0.1792+j0.2524 | -0.0529-j0.3026 | 0.2133-j0.0547 | -0.0676+j0.2751 | 0.0901-j0.0367 | -0.1443+j0.0473 |
| 27 | 0.1139+j0.0092 | -0.0909-j0.0273 | 0.1229+j0.1970 | -0.0639+j0.0308 | 0.0871+j0.1886 | 0.1213+j0.1973 | -0.0033+j0.0489 | 0.1698+j0.1548 | 0.0574-j0.1223 |
| 28 | -0.0485+j0.2120 | 0.0683+j0.0433 | -0.1988+j0.2747 | -0.0327+j0.0499 | -0.0810+j0.0120 | -0.1696+j0.3086 | -0.1294+j0.1162 | -0.0707-j0.0577 | 0.0818+j0.0683 |
| 29 | 0.0006+j0.0205 | -0.1055+j0.0668 | 0.0473+j0.0365 | -0.0426-j0.0327 | 0.0934-j0.0558 | -0.0591-j0.0141 | -0.1280+j0.0001 | -0.1228+j0.0759 | 0.1011-j0.1585 |
| 30 | -0.0667+j0.0071 | -0.2471-j0.0933 | -0.0451+j0.1114 | -0.1421-j0.0480 | 0.1699-j0.0469 | 0.0167+j0.0481 | -0.0536-j0.1314 | 0.2568+j0.0969 | -0.0604-j0.0786 |
| 31 | -0.2077-j0.2282 | 0.0682+j0.2381 | -0.1865-j0.1219 | 0.0324+j0.1438 | 0.1644-j0.1603 | -0.1727-j0.1232 | 0.0334+j0.1431 | -0.0160+j0.0148 | 0.0911-j0.2836 |
| 32 | -0.1265+j0.0798 | 0.0195-j0.1981 | -0.0820-j0.0034 | 0.0780-j0.0666 | -0.1104+j0.0125 | -0.0513+j0.0157 | 0.0520+j0.0127 | 0.1090-j0.0340 | -0.1751-j0.0192 |
| 33 | 0.0276+j0.1123 | -0.0465+j0.0036 | -0.1170+j0.0836 | -0.1150-j0.0442 | 0.0423-j0.0163 | -0.1042+j0.1508 | -0.0859-j0.0728 | -0.0061+j0.2155 | 0.0056+j0.1524 |
| 34 | -0.0043+j0.1419 | -0.0331+j0.0257 | 0.0354+j0.0839 | 0.1399+j0.0277 | 0.0720+j0.0480 | 0.0128+j0.0261 | -0.0147+j0.0550 | 0.0134+j0.0477 | 0.0249-j0.0000 |
| 35 | 0.0147-j0.0002 | 0.1589+j0.0603 | 0.2146+j0.0002 | 0.0795+j0.0892 | 0.0027-j0.0066 | 0.1502+j0.0075 | 0.1340+j0.2318 | 0.0510+j0.0546 | -0.1729+j0.0337 |
| 36 | 0.0066-j0.0353 | 0.0641+j0.1233 | 0.1105-j0.1351 | -0.0085-j0.0374 | -0.0916+j0.0016 | 0.1558-j0.0742 | -0.0182-j0.0708 | -0.0063+j0.0183 | -0.0397-j0.0840 |
| 37 | -0.1775+j0.1532 | 0.0678+j0.1191 | -0.0920+j0.0875 | 0.0953+j0.0980 | -0.0783+j0.2550 | -0.1810+j0.0746 | 0.0938+j0.1883 | -0.0733+j0.1909 | -0.0398-j0.3157 |
| 38 | -0.0491+j0.0762 | 0.0271-j0.2271 | -0.0300-j0.1244 | 0.1254-j0.1780 | -0.1807+j0.1094 | 0.0573-j0.0604 | 0.0505-j0.0878 | -0.0475+j0.1187 | 0.2074-j0.0389 |
| 39 | -0.1185-j0.1370 | 0.0877+j0.1282 | -0.1987-j0.0400 | -0.1259+j0.0849 | 0.0347+j0.1010 | -0.1213-j0.1572 | -0.0316+j0.0609 | -0.0415+j0.1335 | -0.0265+j0.2476 |
| 40 | 0.1381+j0.1197 | -0.1054+j0.0719 | 0.0853+j0.0506 | -0.1303+j0.0004 | -0.0434+j0.1560 | -0.0473+j0.2651 | -0.1373+j0.0291 | 0.0628+j0.1182 | 0.2462-j0.1978 |
| 41 | 0.0402-j0.1385 | 0.1926-j0.0134 | -0.1360-j0.1131 | 0.1888+j0.0584 | 0.0427+j0.1170 | -0.1701-j0.1300 | 0.2823+j0.0664 | -0.0947+j0.0036 | 0.1360+j0.1081 |
| 42 | -0.0414-j0.0215 | 0.0272-j0.0083 | 0.0036+j0.0701 | -0.1031-j0.0692 | -0.0744-j0.0089 | -0.0475+j0.0891 | 0.0269-j0.0262 | 0.0648-j0.2780 | 0.0269+j0.0323 |
| 43 | 0.0425-j0.2408 | -0.0126+j0.0324 | 0.1415-j0.1823 | -0.0871-j0.0654 | -0.1619-j0.0234 | 0.0860-j0.1701 | -0.0174-j0.0057 | -0.0856+j0.0200 | 0.0348-j0.1474 |
| 44 | 0.0778+j0.1461 | 0.1290-j0.0779 | -0.0022+j0.1309 | -0.0039-j0.0491 | 0.1864+j0.1523 | 0.0287-j0.0118 | 0.0651-j0.0408 | 0.0757+j0.0776 | -0.0682-j0.0088 |
| 45 | -0.2283+j0.0223 | 0.1207-j0.0885 | -0.1185-j0.1542 | -0.0021+j0.0591 | 0.1173-j0.0573 | -0.2152-j0.1151 | 0.1702+j0.0152 | 0.0913-j0.1074 | 0.0387-j0.0759 |
| 46 | 0.0196+j0.0578 | -0.0827-j0.1182 | 0.0331-j0.0297 | -0.1821-j0.1699 | -0.0136+j0.0547 | 0.0911-j0.0229 | -0.1067-j0.1807 | -0.0469-j0.0884 | -0.0351+j0.1037 |
| 47 | -0.0309-j0.1078 | -0.0020-j0.0275 | -0.0268-j0.0252 | -0.0221+j0.0450 | -0.0126-j0.0084 | 0.0227+j0.0191 | -0.0661-j0.0909 | 0.0390-j0.2093 | -0.1447-j0.0196 |
| 48 | 0.0340+j0.0156 | 0.0280-j0.0564 | 0.1085+j0.1090 | -0.1060+j0.1698 | -0.0269+j0.0097 | 0.0164+j0.0224 | -0.1148+j0.1257 | 0.0610-j0.1203 | -0.1227-j0.0640 |
| 49 | 0.0431-j0.0505 | -0.1056-j0.0500 | -0.1165-j0.0823 | 0.0634+j0.0286 | 0.1539+j0.0925 | -0.0265-j0.0111 | -0.0864-j0.0229 | 0.0021+j0.1465 | 0.0076-j0.1253 |
| 50 | -0.0656-j0.1008 | -0.1652-j0.0210 | 0.0427-j0.0327 | 0.0531+j0.0341 | -0.0388+j0.0407 | -0.0469-j0.0784 | -0.0557-j0.0173 | -0.0649+j0.0788 | -0.0569-j0.0363 |
| 51 | 0.0719+j0.1280 | -0.0103+j0.1312 | -0.0317-j0.0209 | 0.0299+j0.0984 | -0.0974+j0.1576 | -0.0250+j0.1309 | -0.0489+j0.1720 | -0.2232+j0.0983 | -0.0810-j0.0190 |
| 52 | -0.0367-j0.0387 | -0.0025+j0.0292 | -0.0064+j0.0446 | 0.0960-j0.0295 | -0.0565+j0.0087 | -0.0179-j0.0898 | 0.0189+j0.0422 | 0.0063-j0.0601 | -0.0890-j0.1005 |
| 53 | 0.0549+j0.0875 | 0.0094-j0.0186 | -0.0394+j0.0371 | 0.1152-j0.0318 | -0.1553-j0.1074 | 0.0119+j0.0266 | 0.1237+j0.0095 | -0.0743-j0.1217 | -0.0343+j0.0293 |

| n | $N_{TX}$=2 | | $N_{TX}$=3 | | | $N_{TX}$=4 | | | |
|---|---|---|---|---|---|---|---|---|---|
| | h1 | h2 | h1 | h2 | h3 | h1 | h2 | h3 | h4 |
| 54 | -0.0199-j0.0339 | 0.0529+j0.0211 | 0.0534-j0.0665 | -0.0462-j0.0994 | 0.0834+j0.0164 | 0.0177-j0.0294 | 0.0096+j0.0209 | -0.0850+j0.0442 | -0.0496+j0.0054 |
| 55 | 0.0247-j0.0080 | 0.0285+j0.0582 | 0.0524+j0.0609 | -0.0231-j0.0581 | 0.1502-j0.0071 | 0.0367-j0.0083 | -0.0192-j0.0478 | 0.0500-j0.0122 | -0.0468-j0.0352 |
| 56 | -0.0482-j0.0159 | 0.0386-j0.0935 | -0.0057-j0.0144 | -0.0681+j0.0278 | 0.1019+j0.1022 | -0.0132-j0.0501 | 0.0511-j0.0060 | 0.0083+j0.0355 | 0.0064-j0.0181 |
| 57 | 0.0474-j0.0310 | 0.0283-j0.0598 | 0.0164+j0.0052 | -0.0226+j0.0018 | 0.0256+j0.0919 | 0.0458-j0.0252 | 0.0123+j0.0400 | 0.0793+j0.0643 | -0.0094+j0.0168 |
| 58 | -0.0262+j0.0055 | -0.0550+j0.0053 | -0.0345-j0.0144 | -0.0124-j0.0168 | -0.0529+j0.0828 | -0.0354+j0.0197 | -0.0456-j0.0497 | 0.0799+j0.0421 | 0.0138+j0.0256 |
| 59 | -0.0185-j0.0061 | 0.0113-j0.0073 | 0.0396+j0.0416 | -0.0306+j0.0504 | -0.0240+j0.0590 | 0.0074+j0.0287 | -0.0084+j0.0188 | -0.0598+j0.0669 | -0.0331+j0.1121 |
| 60 | 0.0547+j0.0236 | -0.0100-j0.0336 | -0.0661+j0.0017 | -0.0153+j0.0185 | -0.0182-j0.0669 | 0.0374+j0.0192 | -0.0052+j0.0608 | -0.0535-j0.0376 | 0.0025+j0.0350 |
| 61 | -0.0084+j0.0174 | -0.0605+j0.0318 | 0.0363+j0.0182 | 0.0665-j0.0023 | -0.0049-j0.0340 | 0.0393-j0.0109 | 0.0208-j0.0086 | -0.0449-j0.0622 | 0.0306+j0.0165 |
| 62 | 0.0030+j0.0153 | -0.0212+j0.0315 | 0.0092-j0.0382 | -0.0147-j0.0080 | 0.0299-j0.0039 | -0.0036-j0.0001 | 0.0235-j0.0157 | 0.0532-j0.0191 | 0.0001+j0.0608 |
| 63 | -0.0339-j0.0449 | 0.0100+j0.0136 | 0.0467+j0.0337 | -0.0025-j0.0243 | -0.0036-j0.0072 | -0.0159-j0.0341 | -0.0051+j0.0114 | 0.0824-j0.0414 | -0.0023-j0.0119 |

**Table J.1.2** Time Domain Impulse Response Vectors for $N_{MISO}$=256

| n | $N_{TX}$=2 | | $N_{TX}$=3 | | | $N_{TX}$=4 | | | |
|---|---|---|---|---|---|---|---|---|---|
| | h1 | h2 | h1 | h2 | h3 | h1 | h2 | h3 | h4 |
| 0 | 0.0045+j0.0013 | -0.0073-j0.0104 | 0.0093+j0.0035 | -0.0061-j0.0171 | 0.0090-j0.0232 | 0.0004+j0.0031 | -0.0095-j0.0115 | 0.0211-j0.0237 | -0.0128+j0.0022 |
| 1 | -0.0108-j0.0006 | 0.0166-j0.0106 | -0.0144-j0.0004 | 0.0228-j0.0183 | -0.0063+j0.0283 | -0.0165+j0.0023 | 0.0214-j0.0144 | -0.0070+j0.0292 | -0.0144+j0.0046 |
| 2 | 0.0279-j0.0059 | 0.0135+j0.0047 | 0.0299-j0.0033 | 0.0092-j0.0013 | 0.0035-j0.0104 | 0.0245-j0.0058 | 0.0091-j0.0007 | 0.0116-j0.0123 | 0.0102-j0.0130 |
| 3 | 0.0071+j0.0211 | 0.0036-j0.0299 | 0.0160+j0.0102 | -0.0034-j0.0253 | -0.0032+j0.0081 | 0.0167+j0.0009 | -0.0083-j0.0244 | -0.0091+j0.0070 | 0.0048-j0.0072 |
| 4 | 0.0110+j0.0023 | -0.0134-j0.0009 | 0.0199+j0.0220 | -0.0078+j0.0053 | 0.0186+j0.0177 | 0.0120+j0.0131 | -0.0058+j0.0098 | 0.0220+j0.0165 | 0.0065-j0.0035 |
| 5 | 0.0030+j0.0203 | -0.0218+j0.0179 | -0.0067+j0.0215 | -0.0151+j0.0060 | 0.0051-j0.0115 | -0.0032+j0.0200 | -0.0153+j0.0044 | -0.0054-j0.0128 | 0.0098+j0.0061 |
| 6 | 0.0056-j0.0249 | 0.0187-j0.0170 | 0.0100-j0.0293 | 0.0271-j0.0174 | 0.0117+j0.0091 | -0.0019-j0.0154 | 0.0193-j0.0141 | 0.0086+j0.0114 | -0.0074+j0.0324 |
| 7 | 0.0092-j0.0039 | 0.0149-j0.0003 | 0.0134-j0.0010 | 0.0351+j0.0050 | -0.0202-j0.0270 | 0.0200+j0.0029 | 0.0248+j0.0116 | -0.0135-j0.0310 | -0.0179-j0.0038 |
| 8 | -0.0148-j0.0216 | -0.0432+j0.0004 | -0.0009-j0.0266 | -0.0410+j0.0009 | -0.0039+j0.0029 | 0.0042-j0.0238 | -0.0403+j0.0087 | -0.0046+j0.0073 | -0.0142-j0.0178 |
| 9 | 0.0227+j0.0006 | 0.0045-j0.0103 | 0.0204-j0.0031 | 0.0096+j0.0047 | 0.0039-j0.0035 | 0.0157-j0.0064 | 0.0065-j0.0029 | -0.0007-j0.0182 | 0.0133+j0.0090 |
| 10 | -0.0354+j0.0028 | -0.0252+j0.0062 | -0.0355-j0.0003 | -0.0122+j0.0075 | -0.0183-j0.0057 | -0.0295-j0.0042 | -0.0225+j0.0106 | -0.0266+j0.0079 | 0.0004-j0.0078 |
| 11 | 0.0068-j0.0218 | 0.0069-j0.0264 | 0.0197-j0.0093 | 0.0137-j0.0335 | 0.0455+j0.0020 | 0.0148-j0.0095 | 0.0148-j0.0256 | 0.0448+j0.0005 | -0.0136-j0.0148 |
| 12 | -0.0016+j0.0243 | 0.0301-j0.0145 | 0.0086+j0.0150 | 0.0226+j0.0110 | -0.0392+j0.0015 | 0.0146+j0.0196 | 0.0306+j0.0029 | -0.0357+j0.0075 | 0.0230-j0.0002 |
| 13 | 0.0215+j0.0011 | -0.0007-j0.0090 | 0.0244-j0.0167 | -0.0041-j0.0116 | 0.0321+j0.0336 | 0.0070-j0.0012 | -0.0124-j0.0195 | 0.0398+j0.0369 | -0.0029+j0.0075 |
| 14 | 0.0128+j0.0190 | -0.0085-j0.0159 | 0.0133+j0.0135 | -0.0114-j0.0232 | 0.0056+j0.0009 | 0.0049+j0.0226 | -0.0092-j0.0208 | 0.0146-j0.0004 | -0.0186-j0.0010 |
| 15 | -0.0170-j0.0274 | 0.0549-j0.0085 | 0.0090-j0.0159 | 0.0509+j0.0034 | -0.0306-j0.0043 | 0.0121-j0.0134 | 0.0573-j0.0050 | -0.0320-j0.0088 | -0.0057-j0.0272 |
| 16 | 0.0130+j0.0133 | -0.0089-j0.0140 | 0.0168+j0.0208 | 0.0064-j0.0086 | -0.0091-j0.0140 | 0.0223+j0.0167 | 0.0105-j0.0097 | -0.0078-j0.0245 | 0.0203+j0.0036 |
| 17 | -0.0226-j0.0192 | 0.0317+j0.0104 | -0.0210-j0.0375 | 0.0288+j0.0066 | -0.0241+j0.0136 | -0.0111-j0.0337 | 0.0427+j0.0125 | -0.0258+j0.0186 | -0.0039+j0.0237 |
| 18 | 0.0310+j0.0146 | 0.0254+j0.0035 | 0.0229+j0.0021 | 0.0295+j0.0044 | 0.0288-j0.0617 | 0.0202-j0.0008 | 0.0247+j0.0039 | 0.0122-j0.0585 | -0.0068+j0.0133 |
| 19 | -0.0464+j0.0068 | 0.0057+j0.0023 | -0.0420+j0.0028 | 0.0101+j0.0048 | -0.0103+j0.0207 | -0.0357+j0.0115 | 0.0036+j0.0034 | -0.0119+j0.0227 | 0.0095-j0.0003 |
| 20 | -0.0146-j0.0082 | -0.0407+j0.0112 | -0.0246+j0.0031 | -0.0181+j0.0293 | -0.0092-j0.0465 | -0.0241+j0.0010 | -0.0096+j0.0298 | -0.0018-j0.0460 | 0.0188+j0.0256 |
| 21 | -0.0006-j0.0058 | 0.0213+j0.0073 | -0.0080-j0.0268 | 0.0283+j0.0201 | 0.0419+j0.0171 | -0.0029-j0.0266 | 0.0317+j0.0184 | 0.0422+j0.0124 | 0.0138+j0.0215 |
| 22 | 0.0176-j0.0200 | -0.0034+j0.0153 | 0.0371-j0.0356 | 0.0050+j0.0085 | -0.0087-j0.0099 | 0.0274-j0.0347 | 0.0046+j0.0082 | -0.0073-j0.0089 | 0.0018-j0.0024 |
| 23 | 0.0024+j0.0210 | -0.0092-j0.0131 | -0.0136+j0.0227 | -0.0110-j0.0237 | -0.0135-j0.0066 | -0.0138+j0.0159 | -0.0107-j0.0248 | -0.0126-j0.0086 | 0.0203-j0.0007 |
| 24 | -0.0225-j0.0259 | 0.0175-j0.0359 | -0.0170-j0.0142 | 0.0366-j0.0282 | 0.0237+j0.0160 | -0.0062-j0.0129 | 0.0334-j0.0321 | 0.0212+j0.0121 | 0.0360+j0.0254 |
| 25 | -0.0081+j0.0521 | 0.0068-j0.0005 | -0.0045+j0.0480 | 0.0072+j0.0156 | -0.0426-j0.0066 | -0.0062+j0.0346 | 0.0025+j0.0164 | -0.0488-j0.0056 | 0.0037+j0.0131 |
| 26 | -0.0164-j0.0158 | 0.0384-j0.0283 | -0.0071-j0.0366 | 0.0320-j0.0332 | 0.0553-j0.0275 | -0.0111-j0.0339 | 0.0374-j0.0319 | 0.0524-j0.0306 | -0.0168+j0.0072 |
| 27 | 0.0399+j0.0106 | 0.0472-j0.0463 | 0.0288+j0.0179 | 0.0196-j0.0537 | -0.0581+j0.0043 | 0.0195+j0.0310 | 0.0079-j0.0462 | -0.0643+j0.0008 | 0.0255-j0.0002 |
| 28 | -0.0185+j0.0221 | 0.0095-j0.0010 | -0.0264+j0.0225 | 0.0318-j0.0046 | 0.0345-j0.0152 | -0.0181+j0.0247 | 0.0337-j0.0101 | 0.0315-j0.0157 | -0.0028-j0.0044 |
| 29 | -0.0036-j0.0069 | 0.0449+j0.0161 | 0.0237-j0.0035 | 0.0559+j0.0270 | -0.0210+j0.0039 | 0.0279-j0.0055 | 0.0577+j0.0256 | -0.0223-j0.0032 | -0.0355-j0.0171 |
| 30 | 0.0136-j0.0067 | 0.1051+j0.0253 | 0.0027-j0.0245 | 0.1062+j0.0272 | -0.0105+j0.0159 | 0.0034-j0.0307 | 0.0958+j0.0245 | -0.0123+j0.0214 | -0.0141-j0.0232 |
| 31 | 0.0455-j0.0925 | -0.0274+j0.0124 | 0.0570-j0.0796 | -0.0388+j0.0178 | 0.0426+j0.0036 | 0.0588-j0.0812 | -0.0413+j0.0127 | 0.0434+j0.0052 | 0.0025+j0.0042 |
| 32 | 0.0238+j0.0229 | 0.0293-j0.0257 | -0.0026+j0.0246 | 0.0426-j0.0314 | -0.0281+j0.0163 | -0.0080+j0.0307 | 0.0530-j0.0345 | -0.0231+j0.0217 | -0.0118+j0.0155 |
| 33 | -0.0113-j0.0309 | -0.0134+j0.0156 | 0.0161-j0.0355 | 0.0089+j0.0377 | 0.0215-j0.0323 | 0.0104-j0.0341 | -0.0017+j0.0302 | 0.0270-j0.0297 | -0.0467-j0.0381 |
| 34 | 0.0486+j0.0256 | 0.0053+j0.0121 | 0.0537+j0.0316 | 0.0225+j0.0198 | -0.0262+j0.0474 | 0.0543+j0.0322 | 0.0160+j0.0250 | -0.0221+j0.0443 | 0.0085+j0.0129 |
| 35 | -0.0266-j0.0014 | 0.0281-j0.0126 | -0.0233-j0.0263 | 0.0222+j0.0202 | 0.0091+j0.0464 | -0.0239-j0.0256 | 0.0101+j0.0312 | 0.0056+j0.0435 | 0.0118+j0.0267 |
| 36 | 0.0609-j0.0451 | -0.0056+j0.0137 | 0.0668-j0.0349 | 0.0023+j0.0194 | -0.0014-j0.0165 | 0.0737-j0.0372 | -0.0038+j0.0149 | -0.0002-j0.0108 | -0.0522+j0.0478 |
| 37 | -0.0094+j0.0148 | -0.0692-j0.0589 | -0.0130+j0.0105 | -0.0601-j0.0445 | -0.0202-j0.0010 | -0.0150+j0.0085 | -0.0561-j0.0541 | -0.0257-j0.0058 | -0.0066+j0.0363 |
| 38 | -0.0168-j0.0255 | 0.1044-j0.0731 | 0.0028-j0.0168 | 0.0963-j0.0611 | -0.0209-j0.0709 | 0.0014-j0.0074 | 0.0918-j0.0501 | -0.0278-j0.0707 | -0.0050-j0.0138 |
| 39 | -0.0434+j0.0156 | -0.0079-j0.0032 | -0.0471-j0.0035 | -0.0236+j0.0244 | -0.0302+j0.0489 | -0.0607-j0.0073 | -0.0360+j0.0266 | -0.0369+j0.0560 | -0.0168+j0.0023 |
| 40 | -0.0064-j0.0473 | 0.0135+j0.0164 | -0.0180-j0.0594 | -0.0036+j0.0153 | 0.0063-j0.0627 | -0.0182-j0.0675 | 0.0022+j0.0090 | 0.0098-j0.0661 | 0.0033-j0.0110 |
| 41 | 0.0249+j0.0037 | 0.0163+j0.0300 | 0.0146-j0.0098 | 0.0120+j0.0385 | -0.0171+j0.0505 | 0.0246+j0.0110 | 0.0212+j0.0352 | -0.0130+j0.0416 | 0.0333-j0.0079 |
| 42 | -0.0279+j0.0322 | 0.0539-j0.0584 | -0.0399+j0.0276 | 0.0571-j0.0499 | -0.0339-j0.0098 | -0.0361+j0.0162 | 0.0541-j0.0472 | -0.0414-j0.0028 | 0.0402+j0.0284 |
| 43 | 0.0254+j0.0327 | 0.0336+j0.0218 | 0.0364+j0.0317 | 0.0250+j0.0444 | 0.0145+j0.0195 | 0.0417+j0.0262 | 0.0411+j0.0436 | 0.0282+j0.0239 | 0.0216+j0.0573 |
| 44 | -0.0553+j0.0010 | 0.0577+j0.0849 | -0.0817-j0.0368 | 0.0264+j0.1035 | 0.0267-j0.0250 | -0.0793-j0.0438 | 0.0226+j0.1087 | 0.0148-j0.0251 | -0.0060-j0.0064 |
| 45 | 0.0388-j0.0333 | 0.0275+j0.0792 | 0.0265-j0.0181 | 0.0474+j0.0883 | -0.0936-j0.0208 | 0.0282-j0.0134 | 0.0453+j0.0905 | -0.0901-j0.0192 | -0.0233+j0.0283 |
| 46 | -0.0175+j0.0221 | 0.0076+j0.0362 | -0.0291+j0.0104 | -0.0033+j0.0433 | 0.0327+j0.0580 | -0.0271+j0.0225 | 0.0125+j0.0543 | 0.0346+j0.0590 | -0.0079+j0.0045 |
| 47 | -0.0027+j0.0341 | -0.0318+j0.0028 | -0.0115+j0.0348 | -0.0500+j0.0338 | -0.0453-j0.0261 | -0.0082+j0.0245 | -0.0285+j0.0339 | -0.0529-j0.0171 | -0.0055-j0.0450 |
| 48 | -0.0651+j0.0130 | 0.0068-j0.0110 | -0.0526+j0.0168 | -0.0017+j0.0269 | 0.0377-j0.0197 | -0.0516+j0.0234 | -0.0091+j0.0193 | 0.0401-j0.0214 | 0.0126-j0.0068 |
| 49 | -0.0144-j0.0090 | -0.0429+j0.0708 | -0.0236-j0.0148 | -0.0472+j0.0554 | -0.1004+j0.0349 | -0.0201-j0.0263 | -0.0279+j0.0665 | -0.1002+j0.0356 | -0.0211+j0.0305 |
| 50 | 0.0138+j0.0292 | 0.0552+j0.0007 | 0.0075+j0.0208 | 0.0348-j0.0027 | 0.0878-j0.0337 | 0.0029+j0.0384 | 0.0298+j0.0005 | 0.0908-j0.0431 | -0.0040+j0.0159 |
| 51 | 0.0051-j0.0164 | -0.0155-j0.0319 | -0.0096-j0.0143 | -0.0051-j0.0271 | 0.0121-j0.0175 | -0.0074-j0.0198 | -0.0094-j0.0321 | 0.0073-j0.0057 | -0.0390-j0.0801 |

| n | $N_{TX}$=2 | | $N_{TX}$=3 | | | $N_{TX}$=4 | | | |
|---|---|---|---|---|---|---|---|---|---|
| | $h_1$ | $h_2$ | $h_1$ | $h_2$ | $h_3$ | $h_1$ | $h_2$ | $h_3$ | $h_4$ |
| 52 | 0.0316-j0.0102 | -0.0311-j0.0200 | 0.0194-j0.0003 | -0.0375-j0.0075 | 0.0215+j0.0272 | 0.0063+j0.0011 | -0.0423+j0.0058 | 0.0238+j0.0227 | -0.0363+j0.0340 |
| 53 | 0.0151-j0.0249 | 0.1112+j0.0758 | -0.0019-j0.0297 | 0.1114+j0.0689 | 0.0574+j0.0202 | -0.0095-j0.0239 | 0.1175+j0.0629 | 0.0621+j0.0123 | 0.0000+j0.0104 |
| 54 | -0.0074+j0.0144 | 0.0359+j0.0300 | -0.0099+j0.0034 | 0.0183+j0.0028 | 0.0233+j0.0823 | -0.0131+j0.0117 | 0.0007+j0.0022 | 0.0217+j0.0780 | -0.0431-j0.0395 |
| 55 | 0.0317-j0.0189 | -0.0004+j0.0000 | 0.0373+j0.0004 | 0.0039-j0.0187 | 0.0185-j0.0212 | 0.0365+j0.0050 | -0.0003-j0.0056 | 0.0150-j0.0200 | 0.0296+j0.0585 |
| 56 | 0.0506+j0.0009 | 0.1122+j0.0658 | 0.0504+j0.0041 | 0.0969+j0.0775 | 0.0251+j0.0704 | 0.0614-j0.0123 | 0.0961+j0.0775 | 0.0298+j0.0636 | 0.0005+j0.0314 |
| 57 | 0.0413+j0.0186 | -0.0340+j0.0650 | 0.0396+j0.0078 | -0.0375+j0.0498 | -0.0387-j0.0211 | 0.0199+j0.0308 | -0.0342+j0.0347 | -0.0417-j0.0142 | -0.0879+j0.0294 |
| 58 | -0.0218-j0.0459 | -0.0472+j0.0367 | -0.0280-j0.0447 | -0.0777+j0.0331 | -0.0156+j0.0313 | -0.0288-j0.0496 | -0.0584+j0.0244 | -0.0049+j0.0294 | 0.0353-j0.0193 |
| 59 | -0.0635-j0.0790 | 0.0490+j0.0665 | -0.0684-j0.0761 | 0.0574+j0.0589 | -0.0131-j0.0118 | -0.0569-j0.0760 | 0.0618+j0.0488 | -0.0120-j0.0143 | 0.0246+j0.0276 |
| 60 | 0.0002-j0.0665 | 0.0144-j0.0037 | 0.0013-j0.0687 | 0.0109-j0.0109 | -0.0195-j0.0356 | -0.0029-j0.0749 | 0.0094-j0.0103 | -0.0142-j0.0272 | 0.0653+j0.0968 |
| 61 | -0.0110+j0.0071 | 0.0780-j0.0095 | -0.0266+j0.0135 | 0.0641-j0.0317 | 0.0014+j0.0456 | -0.0351+j0.0013 | 0.0690-j0.0288 | -0.0087+j0.0500 | 0.0260-j0.0060 |
| 62 | -0.0320+j0.0072 | 0.0143+j0.0539 | -0.0276+j0.0057 | -0.0058+j0.0511 | 0.0110+j0.0026 | -0.0374+j0.0085 | -0.0118+j0.0348 | 0.0184+j0.0114 | 0.0323-j0.0155 |
| 63 | -0.0526-j0.0819 | -0.0611-j0.0106 | -0.0436-j0.0795 | -0.0697-j0.0182 | -0.0485+j0.0302 | -0.0520-j0.0930 | -0.0829-j0.0168 | -0.0512+j0.0293 | 0.0557+j0.0025 |
| 64 | 0.0762-j0.0814 | -0.0369+j0.0393 | 0.0698-j0.0933 | -0.0316+j0.0295 | 0.0904+j0.0699 | 0.0676-j0.0855 | -0.0220+j0.0329 | 0.0972+j0.0890 | 0.0015-j0.0066 |
| 65 | 0.0174+j0.0191 | 0.0945-j0.0140 | 0.0147+j0.0168 | 0.0957-j0.0299 | -0.0286+j0.0004 | 0.0141+j0.0020 | 0.0963-j0.0196 | -0.0258-j0.0021 | -0.0344+j0.0180 |
| 66 | -0.0698-j0.0311 | 0.0182-j0.0327 | -0.0625-j0.0461 | 0.0137-j0.0455 | -0.0297+j0.0070 | -0.0583-j0.0240 | 0.0076-j0.0453 | -0.0160+j0.0054 | -0.0183+j0.0599 |
| 67 | -0.0830-j0.0056 | -0.0032+j0.0410 | -0.0810-j0.0069 | -0.0044+j0.0211 | -0.0921-j0.0328 | -0.0727+j0.0025 | -0.0010+j0.0152 | -0.0876-j0.0250 | -0.0084-j0.0042 |
| 68 | -0.0097-j0.0280 | -0.1006+j0.0134 | -0.0145-j0.0330 | -0.0894+j0.0093 | -0.0425+j0.0557 | -0.0034-j0.0268 | -0.1000+j0.0111 | -0.0553+j0.0453 | -0.0711-j0.0018 |
| 69 | -0.0109-j0.0085 | 0.0526-j0.1420 | -0.0062-j0.0128 | 0.0554-j0.1531 | 0.0766-j0.0651 | -0.0029-j0.0087 | 0.0512-j0.1350 | 0.0790-j0.0639 | -0.0218-j0.0898 |
| 70 | -0.0552+j0.0284 | 0.0129+j0.0012 | -0.0499+j0.0237 | 0.0222-j0.0039 | -0.0009+j0.0275 | -0.0646+j0.0253 | 0.0320+j0.0005 | -0.0140+j0.0222 | -0.0171-j0.0459 |
| 71 | 0.0061+j0.0184 | -0.0032-j0.0237 | -0.0014+j0.0290 | -0.0145-j0.0322 | 0.0874-j0.0547 | -0.0019+j0.0340 | -0.0234-j0.0242 | 0.0795-j0.0535 | 0.0344+j0.0802 |
| 72 | -0.0163+j0.0371 | -0.1229+j0.0849 | -0.0104+j0.0420 | -0.1159+j0.0877 | 0.1048+j0.0251 | -0.0122+j0.0312 | -0.1218+j0.1005 | 0.1055+j0.0278 | -0.0760+j0.0634 |
| 73 | 0.0668+j0.0585 | 0.0452-j0.0062 | 0.0406+j0.0562 | 0.0507+j0.0012 | 0.0894-j0.0730 | 0.0516+j0.0568 | 0.0513+j0.0074 | 0.0957-j0.0663 | -0.0346+j0.0226 |
| 74 | -0.0539-j0.0087 | -0.0511+j0.0225 | -0.0764-j0.0041 | -0.0471+j0.0277 | -0.0084-j0.1051 | -0.0689-j0.0054 | -0.0450+j0.0322 | -0.0064-j0.1034 | -0.0124+j0.0585 |
| 75 | -0.0005+j0.0255 | -0.0449-j0.0377 | 0.0070+j0.0200 | -0.0506-j0.0361 | -0.1391+j0.0839 | 0.0023+j0.0206 | -0.0457-j0.0417 | -0.1420+j0.0702 | -0.0432+j0.0644 |
| 76 | -0.0018+j0.0540 | -0.0078+j0.0208 | 0.0039+j0.0623 | 0.0072+j0.0263 | 0.0437-j0.0193 | 0.0071+j0.0487 | 0.0226+j0.0302 | 0.0524-j0.0166 | -0.0762-j0.0508 |
| 77 | 0.0266+j0.1584 | -0.0057-j0.0098 | 0.0325+j0.1543 | -0.0025-j0.0177 | 0.0022-j0.0410 | 0.0229+j0.1551 | -0.0042-j0.0095 | -0.0174-j0.0368 | -0.0288-j0.0024 |
| 78 | 0.0391-j0.0546 | -0.0526+j0.0390 | 0.0254-j0.0333 | -0.0447+j0.0313 | 0.0307+j0.0856 | 0.0456-j0.0233 | -0.0636+j0.0291 | 0.0305+j0.0873 | 0.0972+j0.0269 |
| 79 | -0.0285-j0.1144 | 0.0603-j0.0091 | -0.0331-j0.1260 | 0.0686+j0.0117 | 0.0037-j0.0202 | -0.0221-j0.1167 | 0.0688+j0.0167 | 0.0137-j0.0178 | 0.0025-j0.0101 |
| 80 | -0.0200-j0.0217 | -0.0054+j0.0590 | -0.0274-j0.0175 | 0.0058+j0.0581 | 0.0605+j0.0380 | -0.0036-j0.0234 | 0.0092+j0.0675 | 0.0631+j0.0323 | 0.0278+j0.0907 |
| 81 | -0.1922+j0.0431 | 0.0583-j0.0276 | -0.1802+j0.0386 | 0.0462-j0.0329 | 0.0200-j0.0606 | -0.1774+j0.0352 | 0.0504-j0.0324 | 0.0218-j0.0448 | 0.0737-j0.0002 |
| 82 | -0.0887-j0.0415 | -0.0347-j0.0286 | -0.0826-j0.0474 | -0.0295+j0.0021 | 0.0209+j0.0041 | -0.0914-j0.0488 | -0.0296+j0.0041 | 0.0269-j0.0052 | -0.0744+j0.0119 |
| 83 | -0.0105-j0.0153 | -0.0600+j0.0194 | -0.0258-j0.0101 | -0.0257+j0.0303 | -0.0083-j0.0650 | -0.0358-j0.0015 | -0.0358+j0.0213 | -0.0200-j0.0671 | -0.0087+j0.0293 |
| 84 | -0.0595-j0.0274 | -0.0010+j0.0072 | -0.0292-j0.0202 | 0.0089-j0.0029 | -0.0048+j0.0147 | -0.0459-j0.0274 | 0.0073-j0.0085 | -0.0154+j0.0155 | 0.0091-j0.0154 |
| 85 | 0.0361-j0.0148 | -0.0057-j0.0407 | 0.0240-j0.0226 | -0.0159-j0.0158 | 0.0523+j0.0753 | 0.0158-j0.0174 | -0.0088-j0.0135 | 0.0603+j0.0687 | -0.0211+j0.0470 |
| 86 | -0.0054+j0.0302 | 0.0432-j0.0783 | 0.0220+j0.0285 | 0.0659-j0.0864 | 0.0217-j0.0103 | 0.0203+j0.0313 | 0.0602-j0.0961 | 0.0208-j0.0089 | -0.0259+j0.0374 |
| 87 | 0.0166-j0.0056 | 0.0234+j0.0464 | 0.0227-j0.0061 | 0.0261+j0.0398 | 0.0224+j0.0076 | 0.0291-j0.0062 | 0.0388+j0.0246 | 0.0244+j0.0041 | -0.0365+j0.0115 |
| 88 | -0.0272-j0.0169 | 0.0314+j0.0385 | -0.0075+j0.0059 | 0.0223+j0.0414 | -0.0859+j0.0419 | -0.0112+j0.0039 | 0.0285+j0.0402 | -0.0808+j0.0414 | -0.1417-j0.0547 |
| 89 | -0.0845+j0.0007 | 0.0422+j0.0630 | -0.0633-j0.0120 | 0.0315+j0.0625 | -0.0562-j0.0692 | -0.0673-j0.0204 | 0.0256+j0.0598 | -0.0620-j0.0623 | -0.0717+j0.0396 |
| 90 | -0.0234+j0.0606 | 0.0459-j0.0138 | -0.0072+j0.0634 | 0.0268-j0.0225 | -0.0042+j0.0299 | -0.0190+j0.0629 | 0.0152-j0.0258 | 0.0037+j0.0448 | 0.0187+j0.0036 |
| 91 | -0.0715-j0.0344 | 0.0434+j0.1201 | -0.0747-j0.0503 | 0.0560+j0.1229 | 0.0196+j0.0285 | -0.0741-j0.0483 | 0.0571+j0.1337 | 0.0269+j0.0228 | -0.0888+j0.0405 |
| 92 | 0.0904+j0.0345 | 0.0294-j0.0702 | 0.1021+j0.0365 | 0.0180-j0.0793 | 0.0202-j0.1407 | 0.0910+j0.0376 | 0.0309-j0.0841 | 0.0126-j0.1322 | -0.0574+j0.0049 |
| 93 | -0.0377-j0.0186 | -0.0677+j0.0032 | -0.0387-j0.0253 | -0.0775-j0.0089 | 0.0079-j0.1756 | -0.0519-j0.0298 | -0.0649-j0.0067 | 0.0072-j0.1659 | -0.0518-j0.0061 |
| 94 | -0.0195-j0.0167 | 0.0379+j0.0265 | -0.0190-j0.0086 | 0.0208+j0.0134 | -0.0528-j0.0365 | -0.0258+j0.0056 | 0.0187+j0.0060 | -0.0507-j0.0395 | 0.0202-j0.0141 |
| 95 | 0.0785+j0.0161 | 0.0332-j0.0218 | 0.0925-j0.0026 | 0.0352-j0.0306 | -0.1356-j0.0097 | 0.0995-j0.0009 | 0.0298-j0.0296 | -0.1385-j0.0139 | -0.0533-j0.0075 |
| 96 | -0.0205+j0.0282 | -0.0077-j0.0185 | -0.0192+j0.0061 | -0.0008-j0.0056 | -0.0179+j0.0041 | -0.0163+j0.0086 | 0.0099-j0.0219 | -0.0272+j0.0014 | 0.0206-j0.0127 |
| 97 | -0.0373-j0.0270 | 0.1006+j0.0250 | -0.0179-j0.0295 | 0.0968+j0.0162 | -0.0175+j0.0530 | -0.0276-j0.0308 | 0.0864+j0.0268 | -0.0127+j0.0379 | 0.0621-j0.1175 |
| 98 | -0.0798+j0.1285 | 0.1501+j0.0007 | -0.0634+j0.1162 | 0.1337-j0.0187 | 0.1435+j0.0091 | -0.0626+j0.1174 | 0.1200-j0.0282 | 0.1341+j0.0126 | -0.1313-j0.0155 |
| 99 | -0.0070+j0.1068 | -0.0057-j0.0668 | -0.0086+j0.1066 | -0.0097-j0.0872 | -0.0251+j0.0045 | -0.0080+j0.1113 | -0.0172-j0.0794 | -0.0116-j0.0024 | -0.0265+j0.0178 |
| 100 | 0.1014+j0.0033 | -0.0199-j0.0404 | 0.1164-j0.0125 | -0.0026-j0.0177 | -0.0297-j0.0197 | 0.1088-j0.0207 | -0.0092-j0.0296 | -0.0320-j0.0221 | -0.0194+j0.0200 |
| 101 | -0.0322-j0.0503 | 0.0267+j0.0521 | -0.0330-j0.0678 | 0.0288+j0.0528 | 0.0118+j0.0239 | -0.0399-j0.0708 | 0.0288+j0.0582 | 0.0143+j0.0308 | 0.0274-j0.0186 |
| 102 | 0.0449+j0.1164 | -0.0138+j0.0048 | 0.0361+j0.1303 | -0.0186+j0.0019 | 0.0001-j0.0607 | 0.0527+j0.1480 | -0.0240+j0.0075 | 0.0050-j0.0549 | 0.0177+j0.0390 |
| 103 | -0.0837+j0.0089 | 0.0307-j0.0880 | -0.0722+j0.0055 | 0.0252-j0.0790 | 0.0362+j0.0672 | -0.0622-j0.0033 | 0.0306-j0.0892 | 0.0392+j0.0657 | -0.0234+j0.0317 |
| 104 | 0.0767-j0.0548 | 0.0652+j0.0565 | 0.0765-j0.0633 | 0.0650+j0.0691 | -0.0078-j0.0508 | 0.0701-j0.0610 | 0.0711+j0.0671 | -0.0081-j0.0568 | 0.0089-j0.0008 |
| 105 | 0.0749+j0.0176 | -0.0290-j0.1216 | 0.0801+j0.0101 | -0.0285-j0.1187 | -0.0297+j0.0046 | 0.0942+j0.0181 | -0.0231-j0.1139 | -0.0231+j0.0137 | -0.0606-j0.0170 |
| 106 | -0.0111-j0.0612 | -0.0985+j0.0166 | -0.0155-j0.0604 | -0.1006+j0.0184 | 0.0222+j0.0018 | -0.0106-j0.0759 | -0.0977+j0.0218 | 0.0250-j0.0043 | -0.0566+j0.0596 |
| 107 | 0.0415+j0.0154 | -0.0584+j0.0611 | 0.0460-j0.0040 | -0.0675+j0.0707 | -0.0378+j0.0158 | 0.0476+j0.0020 | -0.0753+j0.0668 | -0.0278+j0.0171 | 0.0872-j0.1098 |
| 108 | -0.0571+j0.0488 | 0.0113+j0.1151 | -0.0541+j0.0487 | 0.0096+j0.0992 | 0.0262+j0.0463 | -0.0402+j0.0468 | 0.0236+j0.1099 | 0.0166+j0.0358 | 0.0477-j0.0136 |
| 109 | 0.0505+j0.1136 | 0.0194+j0.0388 | 0.0762+j0.1252 | 0.0079+j0.0400 | -0.0882-j0.0328 | 0.0710+j0.1213 | 0.0064+j0.0485 | -0.0774-j0.0310 | 0.0887+j0.0408 |
| 110 | 0.0158+j0.0007 | -0.0285+j0.0831 | 0.0262-j0.0261 | -0.0326+j0.0988 | 0.0488-j0.0531 | 0.0390-j0.0065 | -0.0175+j0.1053 | 0.0464-j0.0477 | 0.1657-j0.0408 |
| 111 | -0.0648+j0.0715 | -0.0233+j0.0246 | -0.0705+j0.0612 | -0.0202+j0.0068 | -0.0234-j0.0290 | -0.0622+j0.0677 | -0.0145+j0.0059 | -0.0226-j0.0205 | -0.0307-j0.0767 |
| 112 | 0.0750+j0.0274 | 0.0403-j0.0920 | 0.0666+j0.0218 | 0.0375-j0.0783 | -0.0133+j0.0278 | 0.0692+j0.0101 | 0.0530-j0.0856 | -0.0268+j0.0262 | -0.0776-j0.0526 |
| 113 | -0.1055-j0.0100 | -0.0303+j0.0736 | -0.0930-j0.0127 | -0.0111+j0.0627 | -0.1071+j0.0391 | -0.0946-j0.0057 | -0.0101+j0.0664 | -0.1065+j0.0432 | -0.0856-j0.0313 |
| 114 | -0.0026+j0.0536 | 0.0705-j0.0641 | -0.0211+j0.0416 | 0.0643-j0.0670 | 0.0277+j0.0094 | -0.0317+j0.0370 | 0.0534-j0.0607 | 0.0427-j0.0003 | -0.0014+j0.0291 |
| 115 | 0.0586+j0.0059 | 0.0103-j0.0475 | 0.0489+j0.0103 | 0.0061-j0.0695 | 0.0234+j0.0454 | 0.0522+j0.0168 | 0.0027-j0.0533 | 0.0213+j0.0455 | 0.0812+j0.0323 |
| 116 | 0.0467+j0.0333 | -0.1161-j0.0656 | 0.0547+j0.0219 | -0.1313-j0.0666 | -0.0869-j0.0849 | 0.0450+j0.0263 | -0.1386-j0.0592 | -0.0832-j0.0728 | -0.0846-j0.1057 |
| 117 | 0.0458-j0.0547 | 0.0182-j0.0046 | 0.0406-j0.0510 | 0.0041+j0.0003 | -0.1123+j0.0835 | 0.0403-j0.0497 | 0.0098-j0.0105 | -0.1055+j0.0820 | -0.0551-j0.0410 |
| 118 | -0.0488+j0.0044 | -0.0357-j0.0162 | -0.0610-j0.0032 | -0.0214-j0.0243 | 0.0058+j0.0668 | -0.0698-j0.0020 | -0.0293-j0.0176 | 0.0307+j0.0616 | -0.0377+j0.0158 |
| 119 | 0.0052-0.1456 | -0.0784-j0.0139 | 0.0174-j0.1520 | -0.0860-j0.0068 | 0.0248-j0.0445 | 0.0136-j0.1523 | -0.1022-j0.0058 | 0.0310-j0.0445 | 0.1031+j0.0823 |
| 120 | -0.0093-j0.0251 | 0.0477-j0.0928 | -0.0048-j0.0278 | 0.0457-j0.0899 | -0.0160+j0.0586 | -0.0092-j0.0333 | 0.0386-j0.0929 | -0.0074+j0.0516 | -0.0074+j0.0167 |

| n | $N_{TX}$=2 | | $N_{TX}$=3 | | | $N_{TX}$=4 | | | |
|---|---|---|---|---|---|---|---|---|---|
| | $h_1$ | $h_2$ | $h_1$ | $h_2$ | $h_3$ | $h_1$ | $h_2$ | $h_3$ | $h_4$ |
| 121 | -0.0297-j0.1343 | -0.0445+j0.0424 | -0.0312-j0.1294 | -0.0288+j0.0457 | 0.0533+j0.1065 | -0.0302-j0.1293 | -0.0250+j0.0395 | 0.0457+j0.1129 | 0.0298+j0.0468 |
| 122 | -0.1614+j0.0594 | 0.1160-j0.0114 | -0.1835+j0.0412 | 0.1070-j0.0230 | -0.0375+j0.0816 | -0.1819+j0.0251 | 0.1014-j0.0147 | -0.0388+j0.0792 | -0.0603-j0.0793 |
| 123 | 0.0151-j0.0335 | -0.0406+j0.0022 | 0.0143-j0.0269 | -0.0502-j0.0085 | 0.1120-j0.0408 | 0.0168-j0.0055 | -0.0455-j0.0205 | 0.1166-j0.0501 | 0.1176+j0.0203 |
| 124 | -0.0481-j0.0023 | -0.0588+j0.0083 | -0.0468-j0.0009 | -0.0755-j0.0086 | 0.0768+j0.0141 | -0.0513+j0.0073 | -0.0699-j0.0078 | 0.0675+j0.0185 | 0.0036+j0.0357 |
| 125 | 0.1284-j0.0284 | 0.1201+j0.0709 | 0.1080-j0.0278 | 0.1177+j0.0525 | -0.1202-j0.0365 | 0.0941-j0.0179 | 0.1111+j0.0509 | -0.1232-j0.0267 | -0.0224+j0.0801 |
| 126 | 0.0053+j0.0053 | 0.0719-j0.0576 | -0.0166+j0.0021 | 0.0503-j0.0514 | -0.0703-j0.0366 | -0.0100-j0.0069 | 0.0550-j0.0562 | -0.0747-j0.0479 | -0.0650+j0.0651 |
| 127 | 0.0109+j0.0756 | 0.0269-j0.0645 | 0.0001+j0.0837 | 0.0223-j0.0592 | -0.0003-j0.0631 | 0.0060+j0.0862 | 0.0116-j0.0573 | -0.0015-j0.0661 | -0.0464+j0.0179 |
| 128 | 0.0179+j0.0187 | -0.0094-j0.0132 | 0.0418+j0.0247 | 0.0022-j0.0192 | -0.0174-j0.0283 | 0.0444+j0.0322 | 0.0005-j0.0406 | -0.0185-j0.0200 | -0.0845+j0.1009 |
| 129 | -0.0849+j0.0130 | -0.0260+j0.0080 | -0.0937+j0.0054 | -0.0135-j0.0044 | -0.0231-j0.0272 | -0.0899+j0.0144 | -0.0107-j0.0072 | -0.0255-j0.0336 | 0.0186+j0.0074 |
| 130 | 0.0319-j0.0024 | 0.0712+j0.0184 | 0.0022-j0.0310 | 0.0899+j0.0276 | 0.0753-j0.0495 | -0.0003-j0.0191 | 0.0956+j0.0168 | 0.0772-j0.0365 | -0.0049+j0.0505 |
| 131 | 0.0061-j0.0114 | -0.0098-j0.0490 | 0.0079-j0.0270 | -0.0168-j0.0333 | 0.0223+j0.1358 | 0.0013-j0.0402 | -0.0160-j0.0290 | 0.0150+j0.1393 | -0.0724+j0.0740 |
| 132 | -0.0701+j0.0393 | 0.0169-j0.0200 | -0.0614+j0.0397 | 0.0201-j0.0270 | -0.0420+j0.0580 | -0.0732+j0.0329 | 0.0138-j0.0271 | -0.0412+j0.0707 | -0.0311-j0.0019 |
| 133 | 0.0817+j0.0911 | 0.0203+j0.0482 | 0.0787+j0.0843 | 0.0118+j0.0374 | -0.0073+j0.0303 | 0.0754+j0.0799 | 0.0265+j0.0422 | 0.0105+j0.0223 | 0.0256+j0.0078 |
| 134 | -0.0037+j0.0605 | -0.0081+j0.1039 | -0.0033+j0.0474 | -0.0057+j0.1278 | -0.0350-j0.0312 | 0.0019+j0.0442 | -0.0136+j0.1175 | -0.0414-j0.0247 | 0.1163-j0.0532 |
| 135 | -0.1555+j0.1231 | -0.0098+j0.0478 | -0.1693+j0.1235 | -0.0035+j0.0442 | -0.0489-j0.0041 | -0.1632+j0.1292 | 0.0113+j0.0467 | -0.0508-j0.0152 | -0.0193-j0.0867 |
| 136 | 0.0104-j0.0311 | 0.0522-j0.1121 | 0.0122-j0.0348 | 0.0435-j0.0966 | -0.0194-j0.0817 | -0.0033-j0.0291 | 0.0348-j0.0961 | -0.0168-j0.0904 | 0.1069+j0.0163 |
| 137 | 0.0484-j0.0483 | 0.0408+j0.0629 | 0.0387-j0.0324 | 0.0481+j0.0619 | 0.0573+j0.0646 | 0.0383-j0.0287 | 0.0489+j0.0669 | 0.0574+j0.0713 | 0.0417-j0.0084 |
| 138 | -0.0707-j0.0378 | -0.0345+j0.0585 | -0.0448-j0.0390 | -0.0270+j0.0647 | 0.0364-j0.0137 | -0.0484-j0.0328 | -0.0121+j0.0693 | 0.0329-j0.0123 | -0.1473-j0.0163 |
| 139 | -0.0296-j0.0045 | -0.0329+j0.0637 | -0.0475-j0.0173 | -0.0510+j0.0717 | 0.0049+j0.0492 | -0.0322-j0.0234 | -0.0607+j0.0727 | -0.0088+j0.0524 | 0.0471+j0.0245 |
| 140 | 0.0104-j0.0154 | 0.0160-j0.0203 | -0.0027-j0.0088 | 0.0150-j0.0242 | -0.1662-j0.0627 | -0.0061-j0.0265 | 0.0182-j0.0324 | -0.1721-j0.0558 | -0.0345+j0.0275 |
| 141 | -0.0072-j0.0372 | -0.0493-j0.0943 | -0.0096-j0.0209 | -0.0541-j0.0933 | -0.0128-j0.0749 | -0.0050-j0.0108 | -0.0608-j0.0964 | -0.0176-j0.0641 | 0.0811-j0.0023 |
| 142 | -0.0587+j0.0054 | 0.0236-j0.0585 | -0.0452-j0.0022 | 0.0074-j0.0543 | 0.0567-j0.0294 | -0.0351+j0.0002 | 0.0113-j0.0474 | 0.0461-j0.0371 | 0.0889-j0.0048 |
| 143 | -0.0199+j0.2233 | -0.0631+j0.0471 | -0.0217+j0.2017 | -0.0476+j0.0423 | 0.0623+j0.1011 | -0.0227+j0.2009 | -0.0469+j0.0469 | 0.0703+j0.1032 | 0.0584+j0.0125 |
| 144 | 0.0575-j0.0194 | 0.0101-j0.0456 | 0.0453-j0.0255 | 0.0045-j0.0336 | -0.0303+j0.0183 | 0.0349-j0.0280 | 0.0054-j0.0206 | -0.0320+j0.0071 | -0.0197-j0.0390 |
| 145 | -0.0081-j0.0201 | -0.0138+j0.0179 | 0.0117-j0.0240 | -0.0098+j0.0224 | 0.0269+j0.0697 | 0.0191-j0.0241 | -0.0110+j0.0124 | 0.0412+j0.0825 | 0.0107-j0.0147 |
| 146 | -0.0102+j0.0222 | -0.0227-j0.0014 | -0.0084+j0.0352 | -0.0402-j0.0055 | -0.0031+j0.0668 | -0.0037+j0.0320 | -0.0400-j0.0097 | 0.0114+j0.0560 | -0.0554-j0.0271 |
| 147 | 0.0369+j0.0553 | 0.0072+j0.0436 | 0.0314+j0.0585 | 0.0088+j0.0368 | 0.0580-j0.0482 | 0.0299+j0.0478 | 0.0029+j0.0327 | 0.0612-j0.0583 | -0.0593-j0.0340 |
| 148 | -0.0254+j0.0855 | 0.0784-j0.0961 | -0.0147+j0.0617 | 0.0933-j0.0768 | 0.0086+j0.0708 | -0.0168+j0.0554 | 0.1017-j0.0656 | -0.0033+j0.0810 | -0.0785-j0.0083 |
| 149 | -0.0859+j0.0052 | -0.0035-j0.0955 | -0.0818+j0.0112 | -0.0030-j0.0857 | 0.0217+j0.0084 | -0.0853+j0.0271 | -0.0125-j0.0844 | 0.0267+j0.0067 | 0.0780-j0.0940 |
| 150 | 0.0024-j0.1180 | 0.0078-j0.0019 | 0.0153-j0.1124 | 0.0169+j0.0099 | -0.0453+j0.0194 | 0.0122-j0.1058 | 0.0095+j0.0143 | -0.0649+j0.0093 | 0.0223+j0.1641 |
| 151 | -0.0433-j0.0601 | 0.0166-j0.0644 | -0.0542-j0.0647 | -0.0096-j0.0692 | -0.0693-j0.0918 | -0.0472-j0.0635 | -0.0060-j0.0671 | -0.0820-j0.0942 | 0.1162-j0.0177 |
| 152 | 0.0338-j0.0535 | 0.0060-j0.0507 | 0.0387-j0.0697 | 0.0046-j0.0480 | -0.0003-j0.0054 | 0.0330-j0.0822 | 0.0098-j0.0611 | -0.0005-j0.0039 | 0.0019+j0.0079 |
| 153 | 0.0082+j0.0065 | 0.0093-j0.0139 | 0.0013-j0.0080 | -0.0241-j0.0164 | -0.0853-j0.0203 | -0.0081-j0.0194 | -0.0325-j0.0162 | -0.0726-j0.0264 | 0.0028-j0.0016 |
| 154 | 0.0114+j0.0212 | 0.0398+j0.0278 | 0.0163+j0.0258 | 0.0245+j0.0362 | -0.0377+j0.0002 | 0.0177+j0.0373 | 0.0254+j0.0433 | -0.0392-j0.0038 | -0.0185+j0.0874 |
| 155 | 0.0669+j0.0914 | 0.0575-j0.0057 | 0.0604+j0.0681 | 0.0285+j0.0048 | -0.0319-j0.1253 | 0.0732+j0.0810 | 0.0294+j0.0107 | -0.0386-j0.1308 | -0.0081-j0.0029 |
| 156 | -0.0076-j0.0434 | -0.0053-j0.0052 | -0.0043-j0.0310 | -0.0206+j0.0028 | 0.0039-j0.0257 | -0.0119-j0.0275 | -0.0319+j0.0160 | 0.0072-j0.0195 | -0.1267-j0.0138 |
| 157 | -0.1692-j0.0465 | 0.0534-j0.0198 | -0.1639-j0.0362 | 0.0289-j0.0211 | -0.0704+j0.0516 | -0.1534-j0.0349 | 0.0346-j0.0148 | -0.0786+j0.0574 | 0.0145+j0.0262 |
| 158 | 0.0061-j0.0173 | -0.0734+j0.0097 | 0.0066-j0.0128 | -0.0816+j0.0201 | 0.0259+j0.0011 | 0.0106-j0.0138 | -0.0849+j0.0119 | 0.0202-j0.0029 | -0.0726+j0.0598 |
| 159 | -0.0372+j0.0321 | -0.1609+j0.0359 | -0.0273+j0.0416 | -0.1449+j0.0270 | 0.0336-j0.0439 | -0.0240+j0.0397 | -0.1517+j0.0193 | 0.0342-j0.0378 | 0.0454+j0.0474 |
| 160 | -0.0847+j0.0183 | -0.0013-j0.1555 | -0.0722+j0.0292 | -0.0024-j0.1677 | -0.0019+j0.1157 | -0.0689+j0.0332 | -0.0099-j0.1525 | -0.0011+j0.1198 | -0.0273+j0.0298 |
| 161 | -0.0148+j0.0309 | -0.0824+j0.0782 | -0.0326+j0.0257 | -0.0629+j0.0872 | 0.0170+j0.1459 | -0.0435+j0.0261 | -0.0549+j0.0977 | 0.0202+j0.1299 | -0.0009-j0.0804 |
| 162 | -0.1216-j0.0398 | 0.0067+j0.0088 | -0.1075-j0.0301 | 0.0209-j0.0268 | 0.0538+j0.0024 | -0.1036-j0.0213 | 0.0163-j0.0293 | 0.0584+j0.0041 | -0.0094+j0.0020 |
| 163 | 0.0472-j0.0588 | -0.0857+j0.0026 | 0.0540-j0.0550 | -0.0689-j0.0030 | -0.0130+j0.0329 | 0.0646-j0.0473 | -0.0692-j0.0100 | -0.0159+j0.0202 | -0.0091+j0.0600 |
| 164 | -0.0243-j0.0721 | -0.0223+j0.0247 | -0.0210-j0.0760 | -0.0246+j0.0289 | 0.0025+j0.0075 | -0.0205-j0.0833 | -0.0214+j0.0268 | 0.0091+j0.0178 | -0.0389-j0.0208 |
| 165 | -0.0627+j0.0034 | 0.0467+j0.0719 | -0.0843+j0.0032 | 0.0570+j0.0683 | 0.0163-j0.0529 | -0.0855+j0.0084 | 0.0630+j0.0659 | 0.0185-j0.0474 | -0.0103-j0.0089 |
| 166 | -0.0449-j0.0218 | -0.0371-j0.0235 | -0.0484-j0.0353 | -0.0236+j0.0091 | 0.0152+j0.1191 | -0.0499-j0.0329 | -0.0328+j0.0053 | 0.0144+j0.1223 | -0.0351+j0.0082 |
| 167 | 0.0586-j0.0129 | 0.1241-j0.0040 | 0.0611-j0.0004 | 0.1468-j0.0052 | 0.0377+j0.0726 | 0.0729-j0.0157 | 0.1390-j0.0042 | 0.0401+j0.0643 | 0.0990-j0.0370 |
| 168 | -0.0841-j0.1519 | -0.0691-j0.0179 | -0.0873-j0.1528 | -0.0256-j0.0040 | 0.0256-j0.0046 | -0.0924-j0.1429 | -0.0129+j0.0032 | 0.0179+j0.0047 | 0.0110+j0.0131 |
| 169 | 0.1192+j0.0433 | -0.0694-j0.0322 | 0.1130+j0.0324 | -0.0394-j0.0396 | -0.0175+j0.0525 | 0.1104+j0.0347 | -0.0456-j0.0309 | -0.0192+j0.0552 | -0.1548-j0.0949 |
| 170 | 0.0221-j0.0551 | -0.0237-j0.0702 | 0.0239-j0.0506 | -0.0086-j0.0762 | -0.0248-j0.0085 | 0.0309-j0.0577 | -0.0114-j0.0780 | -0.0144-j0.0140 | 0.1390+j0.0395 |
| 171 | 0.0011-j0.0331 | -0.0382-j0.0010 | -0.0057-j0.0426 | -0.0559-j0.0037 | 0.0992+j0.0558 | -0.0019-j0.0302 | -0.0361-j0.0061 | 0.0939+j0.0553 | 0.0637+j0.0974 |
| 172 | 0.0077+j0.0482 | 0.0987+j0.0983 | 0.0094+j0.0433 | 0.0971+j0.0881 | 0.0660+j0.0236 | -0.0015+j0.0362 | 0.1016+j0.0845 | 0.0667+j0.0266 | 0.1185-j0.0294 |
| 173 | 0.0634+j0.0303 | 0.0142+j0.0170 | 0.0779+j0.0424 | -0.0250+j0.0422 | -0.0761+j0.0151 | 0.0603+j0.0414 | -0.0185+j0.0375 | -0.0589+j0.0117 | -0.0497-j0.0050 |
| 174 | -0.0655-j0.0616 | 0.0795+j0.0375 | -0.0453-j0.0686 | 0.0617+j0.0549 | 0.0410-j0.0222 | -0.0494-j0.0734 | 0.0561+j0.0548 | 0.0418-j0.0183 | 0.0020+j0.0127 |
| 175 | -0.0098-j0.0318 | -0.0703-j0.0213 | -0.0141-j0.0384 | -0.0982+j0.0005 | 0.0590+j0.0093 | -0.0120-j0.0379 | -0.0945+j0.0013 | 0.0583+j0.0065 | 0.0349+j0.0165 |
| 176 | 0.0003-j0.0170 | 0.0191-j0.0326 | 0.0009-j0.0171 | 0.0371-j0.0353 | -0.0004+j0.0330 | 0.0004-j0.0254 | 0.0399-j0.0431 | 0.0014+j0.0365 | 0.0555-j0.0116 |
| 177 | -0.0281+j0.0317 | -0.0402-j0.0195 | -0.0260+j0.0515 | -0.0202-j0.0135 | 0.0649+j0.0620 | -0.0266+j0.0435 | -0.0148-j0.0108 | 0.0670+j0.0566 | -0.0109+j0.0746 |
| 178 | -0.0389+j0.0493 | -0.0722-j0.0347 | -0.0537+j0.0259 | -0.0738-j0.0271 | -0.0426-j0.0069 | -0.0488+j0.0352 | -0.0760-j0.0227 | -0.0439-j0.0116 | -0.0719+j0.0407 |
| 179 | 0.0888+j0.0021 | 0.0038+j0.0505 | 0.1000-j0.0170 | -0.0150+j0.0348 | -0.0110+j0.0108 | 0.1058-j0.0267 | -0.0134+j0.0459 | -0.0124+j0.0081 | 0.0912-j0.0295 |
| 180 | 0.0174-j0.0422 | -0.0703+j0.0704 | 0.0177-j0.0343 | -0.0879+j0.0849 | 0.0210-j0.0116 | 0.0173-j0.0380 | -0.0696+j0.0830 | 0.0177-j0.0023 | -0.1047-j0.0247 |
| 181 | 0.0724+j0.0211 | -0.0400+j0.0791 | 0.0729+j0.0267 | -0.0230+j0.0642 | -0.0669+j0.0569 | 0.0812+j0.0322 | -0.0221+j0.0703 | -0.0724+j0.0590 | 0.0595-j0.0057 |
| 182 | 0.0177+j0.0137 | -0.0438-j0.1108 | 0.0347-j0.0025 | -0.0425-j0.1001 | 0.0071-j0.0049 | 0.0258+j0.0056 | -0.0422-j0.1036 | 0.0115-j0.0082 | 0.0540-j0.0299 |
| 183 | 0.0176+j0.0210 | 0.0007+j0.0204 | 0.0127+j0.0253 | 0.0341+j0.0200 | -0.0207-j0.0154 | 0.0144+j0.0159 | 0.0373+j0.0137 | -0.0267+j0.0039 | -0.0337-j0.0118 |
| 184 | 0.0103+j0.0242 | -0.0389-j0.0243 | 0.0169+j0.0058 | -0.0240-j0.0101 | -0.0979+j0.0411 | 0.0149+j0.0106 | -0.0222-j0.0047 | -0.0838+j0.0484 | 0.0949-j0.0806 |
| 185 | -0.0493-j0.0425 | 0.0136-j0.0136 | -0.0396-j0.0369 | 0.0172+j0.0061 | 0.0491+j0.0319 | -0.0484-j0.0422 | 0.0168+j0.0170 | 0.0519+j0.0317 | -0.0282+j0.0736 |
| 186 | 0.0317-j0.0938 | 0.1022+j0.0397 | 0.0277-j0.0957 | 0.1050+j0.0404 | -0.0284+j0.0140 | 0.0146-j0.0976 | 0.1070+j0.0484 | -0.0288+j0.0090 | 0.0260-j0.0386 |
| 187 | 0.0321+j0.0157 | 0.0214+j0.1137 | 0.0200+j0.0116 | 0.0082+j0.1332 | -0.0762+j0.0748 | 0.0217+j0.0224 | 0.0021+j0.1277 | -0.0736+j0.0737 | 0.0868+j0.0786 |
| 188 | -0.0674-j0.0269 | -0.0226+j0.0733 | -0.0572-j0.0277 | -0.0019+j0.0629 | -0.0723+j0.0291 | -0.0622-j0.0254 | 0.0101+j0.0724 | -0.0842+j0.0166 | -0.0041-j0.0161 |
| 189 | 0.0594+j0.0010 | -0.0638-j0.0740 | 0.0446-j0.0165 | -0.0665-j0.0687 | -0.1319-j0.0100 | 0.0412-j0.0070 | -0.0653-j0.0750 | -0.1247-j0.0084 | -0.0439-j0.0327 |

| n | $N_{TX}$=2 | | $N_{TX}$=3 | | | $N_{TX}$=4 | | | |
|---|---|---|---|---|---|---|---|---|---|
| | $h_1$ | $h_2$ | $h_1$ | $h_2$ | $h_3$ | $h_1$ | $h_2$ | $h_3$ | $h_4$ |
| 190 | 0.0275+j0.0796 | 0.0503+j0.0227 | 0.0166+j0.0693 | 0.0794+j0.0071 | -0.0602-j0.0470 | 0.0223+j0.0752 | 0.0776+j0.0021 | -0.0482-j0.0541 | -0.0150-j0.1164 |
| 191 | -0.0422+j0.0024 | 0.0187-j0.0026 | -0.0497+j0.0294 | 0.0007-j0.0082 | 0.0365-j0.0101 | -0.0536+j0.0136 | -0.0003-j0.0222 | 0.0330-j0.0078 | -0.0010+j0.0316 |
| 192 | 0.0128-j0.0425 | 0.0239-j0.0151 | 0.0200-j0.0486 | 0.0285-j0.0298 | -0.0518+j0.0999 | 0.0261-j0.0386 | 0.0137-j0.0263 | -0.0502+j0.1074 | -0.0402-j0.0263 |
| 193 | 0.0095+j0.0124 | 0.0727+j0.0336 | 0.0217+j0.0014 | 0.0588+j0.0246 | -0.0264-j0.0501 | 0.0222-j0.0023 | 0.0611+j0.0247 | -0.0202-j0.0499 | 0.0195-j0.0416 |
| 194 | -0.0093-j0.0187 | 0.0205+j0.0658 | -0.0288-j0.0162 | -0.0006+j0.0671 | -0.0346-j0.0091 | -0.0280-j0.0185 | -0.0122+j0.0609 | -0.0393-j0.0030 | 0.0462-j0.0085 |
| 195 | 0.0284-j0.0222 | 0.0344+j0.0325 | 0.0267-j0.0192 | 0.0164+j0.0152 | -0.0037+j0.0303 | 0.0213-j0.0039 | 0.0219+j0.0131 | -0.0041+j0.0345 | -0.0013+j0.0083 |
| 196 | 0.0003-j0.0051 | -0.0090-j0.0018 | 0.0130-j0.0113 | -0.0104-j0.0073 | 0.0188-j0.0382 | 0.0238-j0.0043 | -0.0120-j0.0151 | 0.0255-j0.0323 | 0.0473-j0.0001 |
| 197 | 0.0309+j0.0301 | 0.0009-j0.0165 | 0.0261+j0.0148 | 0.0115-j0.0268 | -0.0540-j0.0178 | 0.0264+j0.0105 | 0.0236-j0.0190 | -0.0610-j0.0145 | -0.0198-j0.0593 |
| 198 | -0.0119+j0.0321 | -0.0239-j0.0247 | -0.0077+j0.0362 | -0.0158-j0.0287 | 0.0162+j0.0476 | -0.0012+j0.0556 | -0.0021-j0.0433 | 0.0197+j0.0492 | 0.0399+j0.0305 |
| 199 | -0.0168-j0.0029 | 0.0152+j0.0166 | -0.0126-j0.0088 | 0.0239-j0.0027 | 0.0451-j0.0400 | -0.0148-j0.0191 | 0.0209-j0.0087 | 0.0438-j0.0425 | -0.0264-j0.0572 |
| 200 | -0.0005+j0.0212 | -0.0063-j0.0585 | -0.0037+j0.0234 | -0.0232-j0.0698 | -0.0468+j0.0327 | -0.0112+j0.0218 | -0.0177-j0.0797 | -0.0535+j0.0342 | 0.0387-j0.0018 |
| 201 | -0.0300+j0.0279 | -0.0400+j0.0258 | -0.0291+j0.0419 | -0.0193+j0.0157 | -0.0018+j0.0444 | -0.0326+j0.0460 | -0.0266+j0.0221 | 0.0051+j0.0403 | -0.0857+j0.0098 |
| 202 | 0.0030-j0.0286 | 0.0200-j0.0259 | -0.0118-j0.0150 | 0.0189-j0.0266 | 0.0426+j0.0093 | -0.0083-j0.0179 | 0.0276-j0.0203 | 0.0502+j0.0121 | -0.0581-j0.0174 |
| 203 | 0.0259-j0.0401 | -0.0428+j0.0083 | 0.0271-j0.0399 | -0.0346+j0.0221 | -0.0286+j0.0071 | 0.0381-j0.0502 | -0.0296+j0.0109 | -0.0407+j0.0151 | 0.0857-j0.0301 |
| 204 | -0.0012+j0.0127 | 0.0151-j0.0258 | -0.0121+j0.0032 | 0.0152-j0.0248 | -0.0309-j0.0092 | -0.0122+j0.0119 | 0.0119-j0.0177 | -0.0401-j0.0054 | -0.0047+j0.0318 |
| 205 | -0.0093-j0.0073 | 0.0086-j0.0107 | -0.0013-j0.0016 | 0.0249+j0.0116 | 0.0002-j0.0121 | -0.0064+j0.0024 | 0.0224+j0.0098 | 0.0063-j0.0152 | -0.0071-j0.0411 |
| 206 | -0.0100-j0.0059 | 0.0368+j0.0410 | 0.0084-j0.0097 | 0.0519+j0.0550 | 0.0177-j0.0057 | 0.0007-j0.0033 | 0.0411+j0.0575 | 0.0193+j0.0040 | 0.0157-j0.0136 |
| 207 | -0.0290+j0.0482 | 0.0339+j0.0077 | -0.0451+j0.0443 | 0.0259+j0.0332 | 0.0381-j0.0057 | -0.0437+j0.0369 | 0.0389+j0.0251 | 0.0305-j0.0091 | -0.0672-j0.0296 |
| 208 | -0.0415+j0.0294 | -0.0005+j0.0073 | -0.0418+j0.0570 | 0.0395-j0.0015 | -0.0155+j0.0047 | -0.0468+j0.0519 | 0.0300+j0.0071 | -0.0145+j0.0101 | 0.0063+j0.0325 |
| 209 | -0.0072-j0.0452 | 0.0138-j0.0317 | -0.0074-j0.0479 | 0.0087-j0.0280 | -0.0199-j0.0427 | 0.0014-j0.0422 | 0.0106-j0.0328 | -0.0102-j0.0379 | 0.0022+j0.0659 |
| 210 | -0.0037-j0.0259 | -0.0218+j0.0017 | -0.0110-j0.0353 | 0.0015-j0.0216 | 0.0336-j0.0453 | 0.0029-j0.0339 | -0.0148-j0.0189 | 0.0358-j0.0500 | -0.0320-j0.0227 |
| 211 | -0.0238+j0.0300 | -0.0089+j0.0010 | -0.0296+j0.0323 | -0.0233-j0.0243 | 0.0236-j0.0113 | -0.0288+j0.0223 | -0.0229-j0.0278 | 0.0188-j0.0027 | -0.0199-j0.0471 |
| 212 | 0.0270-j0.0398 | 0.0143+j0.0550 | 0.0311-j0.0309 | 0.0148+j0.0589 | 0.0058-j0.0313 | 0.0145-j0.0327 | -0.0030+j0.0476 | 0.0091-j0.0166 | -0.0331+j0.0026 |
| 213 | 0.0298+j0.0227 | 0.0341+j0.0227 | 0.0226+j0.0182 | 0.0122+j0.0175 | 0.0267-j0.0149 | 0.0238+j0.0242 | 0.0127+j0.0214 | 0.0185-j0.0087 | -0.0280-j0.0222 |
| 214 | -0.0142+j0.0130 | -0.0066-j0.0270 | -0.0110+j0.0048 | -0.0142-j0.0128 | -0.0090+j0.0204 | -0.0043+j0.0048 | -0.0086-j0.0198 | -0.0185+j0.0229 | -0.0103-j0.0005 |
| 215 | -0.0046-j0.0189 | 0.0312-j0.0149 | -0.0075-j0.0243 | 0.0437-j0.0276 | -0.0159+j0.0128 | -0.0117-j0.0185 | 0.0357-j0.0229 | -0.0081+j0.0080 | -0.0375-j0.0327 |
| 216 | 0.0017-j0.0298 | 0.0246-j0.0301 | -0.0034-j0.0296 | 0.0127-j0.0329 | 0.0109+j0.0014 | -0.0012-j0.0296 | 0.0305-j0.0416 | 0.0103+j0.0002 | -0.0207-j0.0002 |
| 217 | 0.0026-j0.0097 | 0.0039+j0.0004 | 0.0066-j0.0163 | 0.0097+j0.0065 | -0.0308+j0.0018 | 0.0078-j0.0234 | -0.0011+j0.0044 | -0.0278-j0.0017 | 0.0006-j0.0300 |
| 218 | 0.0260-j0.0108 | 0.0133-j0.0151 | 0.0301-j0.0276 | 0.0053-j0.0199 | -0.0089+j0.0047 | 0.0232-j0.0268 | 0.0051-j0.0390 | -0.0086+j0.0020 | 0.0313-j0.0094 |
| 219 | 0.0105+j0.0164 | -0.0198+j0.0153 | -0.0012+j0.0204 | -0.0337+j0.0096 | -0.0033+j0.0279 | -0.0131+j0.0102 | -0.0337+j0.0131 | -0.0058+j0.0267 | -0.0429+j0.0186 |
| 220 | 0.0120-j0.0159 | -0.0092-j0.0096 | 0.0144-j0.0319 | -0.0270-j0.0152 | -0.0257+j0.0005 | 0.0147-j0.0376 | -0.0243-j0.0181 | -0.0254-j0.0042 | 0.0275+j0.0011 |
| 221 | 0.0331-j0.0039 | -0.0429-j0.0106 | 0.0366-j0.0166 | -0.0427-j0.0096 | -0.0130-j0.0374 | 0.0345-j0.0043 | -0.0384+j0.0004 | -0.0116-j0.0383 | 0.0068+j0.0368 |
| 222 | -0.0298-j0.0136 | 0.0097-j0.0737 | -0.0130-j0.0112 | 0.0130-j0.0695 | 0.0131+j0.0205 | -0.0098-j0.0122 | 0.0128-j0.0635 | 0.0108+j0.0329 | -0.0257-j0.0128 |
| 223 | 0.0280+j0.0142 | 0.0046-j0.0130 | 0.0272+j0.0151 | 0.0180-j0.0115 | -0.0130+j0.0354 | 0.0235-j0.0001 | 0.0252-j0.0093 | -0.0202+j0.0263 | -0.0148+j0.0089 |
| 224 | 0.0106+j0.0348 | 0.0129-j0.0058 | 0.0137+j0.0274 | 0.0152-j0.0091 | -0.0193-j0.0178 | 0.0117+j0.0275 | 0.0063+j0.0004 | -0.0184-j0.0273 | -0.0331+j0.0263 |
| 225 | -0.0280+j0.0100 | 0.0170-j0.0132 | -0.0393+j0.0249 | -0.0013-j0.0065 | -0.0342+j0.0057 | -0.0366+j0.0143 | 0.0024-j0.0111 | -0.0317+j0.0100 | -0.0043+j0.0231 |
| 226 | -0.0124-j0.0233 | -0.0002+j0.0411 | -0.0048-j0.0319 | -0.0011+j0.0314 | 0.0141-j0.0183 | -0.0001-j0.0301 | -0.0090+j0.0421 | 0.0196-j0.0292 | 0.0055+j0.0115 |
| 227 | 0.0088+j0.0097 | -0.0181+j0.0117 | 0.0107+j0.0053 | -0.0328+j0.0188 | 0.0017-j0.0167 | 0.0227+j0.0184 | -0.0289+j0.0131 | -0.0052-j0.0148 | 0.0199-j0.0391 |
| 228 | -0.0110-j0.0159 | -0.0175+j0.0156 | -0.0056-j0.0216 | -0.0220+j0.0128 | -0.0351+j0.0126 | -0.0073-j0.0195 | -0.0206+j0.0193 | -0.0308+j0.0140 | -0.0201+j0.0412 |
| 229 | 0.0194-j0.0227 | 0.0171-j0.0348 | 0.0226-j0.0259 | 0.0021-j0.0353 | -0.0064-j0.0034 | 0.0278-j0.0195 | -0.0057-j0.0389 | -0.0090-j0.0070 | -0.0018+j0.0373 |
| 230 | 0.0193+j0.0144 | -0.0171+j0.0149 | 0.0116+j0.0031 | 0.0068-j0.0003 | 0.0078-j0.0102 | 0.0095-j0.0022 | 0.0056-j0.0005 | 0.0127-j0.0124 | -0.0171+j0.0203 |
| 231 | 0.0087+j0.0212 | -0.0010-j0.0102 | 0.0016+j0.0153 | 0.0081-j0.0041 | -0.0159+j0.0141 | -0.0081+j0.0198 | -0.0024+j0.0033 | -0.0128+j0.0053 | 0.0143-j0.0111 |
| 232 | -0.0011-j0.0032 | -0.0067+j0.0091 | 0.0231-j0.0165 | -0.0087+j0.0017 | -0.0029-j0.0209 | 0.0206-j0.0085 | -0.0068+j0.0040 | -0.0087-j0.0211 | -0.0017+j0.0153 |
| 233 | 0.0008-j0.0128 | 0.0035+j0.0365 | 0.0008-j0.0113 | 0.0058+j0.0142 | 0.0256-j0.0014 | -0.0043-j0.0150 | -0.0015+j0.0212 | 0.0289+j0.0034 | 0.0006+j0.0331 |
| 234 | -0.0143+j0.0075 | -0.0154-j0.0095 | -0.0108+j0.0108 | -0.0212-j0.0038 | -0.0088+j0.0150 | 0.0038+j0.0112 | -0.0220-j0.0047 | -0.0091-j0.0004 | -0.0093+j0.0003 |
| 235 | 0.0067+j0.0023 | -0.0002+j0.0072 | 0.0191+j0.0025 | 0.0021-j0.0034 | -0.0086-j0.0279 | 0.0204+j0.0041 | 0.0031+j0.0026 | -0.0156-j0.0245 | -0.0059-j0.0063 |
| 236 | 0.0048-j0.0023 | 0.0148-j0.0097 | -0.0050+j0.0091 | 0.0088-j0.0018 | -0.0030-j0.0175 | -0.0062-j0.0044 | 0.0070-j0.0146 | 0.0092-j0.0066 | -0.0174+j0.0213 |
| 237 | 0.0019+j0.0119 | -0.0171+j0.0066 | -0.0096+j0.0202 | -0.0041+j0.0040 | 0.0255-j0.0158 | -0.0074+j0.0108 | -0.0035-j0.0004 | 0.0224-j0.0202 | 0.0157+j0.0087 |
| 238 | 0.0062-j0.0109 | 0.0117-j0.0174 | 0.0193-j0.0312 | 0.0154-j0.0112 | 0.0069-j0.0032 | 0.0211-j0.0214 | 0.0091-j0.0077 | 0.0037+j0.0032 | 0.0032+j0.0060 |
| 239 | 0.0046-j0.0070 | -0.0061-j0.0079 | 0.0156-j0.0061 | -0.0038+j0.0045 | -0.0011+j0.0091 | 0.0184-j0.0080 | 0.0033+j0.0068 | 0.0033+j0.0121 | 0.0102-j0.0135 |
| 240 | 0.0029+j0.0001 | -0.0015-j0.0015 | -0.0002-j0.0026 | 0.0004-j0.0105 | -0.0081-j0.0122 | 0.0038+j0.0089 | -0.0061-j0.0087 | -0.0031-j0.0144 | -0.0061+j0.0076 |
| 241 | -0.0022+j0.0163 | -0.0070-j0.0044 | 0.0108+j0.0230 | -0.0160-j0.0010 | -0.0012-j0.0213 | 0.0050+j0.0260 | -0.0139-j0.0002 | -0.0002-j0.0118 | 0.0368+j0.0192 |
| 242 | -0.0295+j0.0057 | -0.0049+j0.0038 | -0.0212+j0.0071 | -0.0099-j0.0058 | 0.0165+j0.0158 | -0.0251+j0.0103 | -0.0114+j0.0032 | 0.0163+j0.0145 | 0.0034+j0.0037 |
| 243 | -0.0101-j0.0004 | -0.0119-j0.0071 | -0.0185-j0.0032 | -0.0224+j0.0001 | 0.0004-j0.0053 | -0.0140-j0.0046 | -0.0124-j0.0053 | 0.0008-j0.0097 | -0.0199-j0.0199 |
| 244 | 0.0114+j0.0042 | -0.0049-j0.0088 | 0.0123-j0.0045 | -0.0095-j0.0042 | -0.0204-j0.0001 | 0.0102-j0.0027 | -0.0035-j0.0025 | -0.0129-j0.0002 | -0.0065-j0.0138 |
| 245 | -0.0068-j0.0129 | 0.0226-j0.0010 | -0.0010-j0.0055 | 0.0204+j0.0067 | -0.0004-j0.0044 | -0.0022+j0.0001 | 0.0208+j0.0024 | -0.0003-j0.0054 | 0.0144+j0.0109 |
| 246 | 0.0088-j0.0014 | -0.0028+j0.0009 | 0.0232-j0.0064 | 0.0001+j0.0198 | 0.0019-j0.0211 | 0.0288+j0.0004 | 0.0006+j0.0152 | 0.0086-j0.0256 | -0.0062+j0.0088 |
| 247 | 0.0313+j0.0246 | 0.0186-j0.0140 | 0.0365+j0.0228 | 0.0130+j0.0022 | 0.0152-j0.0104 | 0.0359+j0.0226 | 0.0058+j0.0051 | 0.0285-j0.0079 | -0.0054+j0.0072 |
| 248 | 0.0066+j0.0117 | 0.0041+j0.0084 | 0.0001+j0.0158 | -0.0015+j0.0081 | 0.0322+j0.0028 | -0.0069+j0.0128 | -0.0016+j0.0084 | 0.0262+j0.0063 | 0.0274-j0.0110 |
| 249 | -0.0040+j0.0040 | -0.0156+j0.0193 | 0.0126+j0.0173 | -0.0116+j0.0104 | -0.0033+j0.0097 | 0.0070+j0.0100 | -0.0100+j0.0088 | -0.0029+j0.0076 | 0.0147-j0.0075 |
| 250 | -0.0100+j0.0104 | -0.0136-j0.0069 | -0.0084+j0.0106 | -0.0090-j0.0136 | -0.0019+j0.0100 | -0.0129+j0.0045 | -0.0045-j0.0140 | 0.0045+j0.0081 | 0.0022-j0.0041 |
| 251 | -0.0125-j0.0134 | -0.0173-j0.0058 | -0.0184-j0.0067 | -0.0215-j0.0125 | 0.0099-j0.0165 | -0.0151-j0.0074 | -0.0190-j0.0092 | 0.0050-j0.0155 | 0.0092-j0.0105 |
| 252 | -0.0138-j0.0121 | 0.0017+j0.0120 | -0.0067-j0.0112 | 0.0023+j0.0051 | 0.0045-j0.0186 | -0.0007-j0.0046 | 0.0034+j0.0046 | -0.0008-j0.0144 | -0.0046+j0.0081 |
| 253 | 0.0010+j0.0004 | -0.0063+j0.0088 | 0.0002+j0.0045 | -0.0128+j0.0100 | 0.0165+j0.0075 | -0.0020+j0.0061 | -0.0031+j0.0174 | 0.0179+j0.0127 | 0.0018-j0.0135 |
| 254 | -0.0000+j0.0090 | 0.0119+j0.0029 | -0.0115+j0.0071 | 0.0076+j0.0087 | 0.0158+j0.0100 | -0.0150+j0.0070 | 0.0075+j0.0059 | 0.0155+j0.0098 | 0.0255+j0.0003 |
| 255 | -0.0002-j0.0013 | 0.0166+j0.0096 | 0.0020-j0.0006 | 0.0229+j0.0085 | -0.0073+j0.0084 | -0.0005-j0.0001 | 0.0212+j0.0115 | -0.0062+j0.0095 | -0.0089+j0.0243 |

# *Annex K*: Channel Bonding

## K.1 INTRODUCTION

In channel bonding, data of a single PLP connection is spread over two or more different RF channels. Primarily channel bonding enables total service data rates that exceed the net capacity of a single RF channel, but it can also be used to exploit the frequency diversity among multiple RF channels. In this Annex the description is of channel bonding for two channels. The two RF channels may be located at any channel frequency, not necessarily adjacent to each other. The use of channel bonding is optional, but when it is used it shall conform to the description in this Annex.

Channel bonding shall not be used with MIMO. Other features are compatible with channel bonding, including but not limited to LDM, PAPR reduction, MISO and so on.

Channel bonding is processed transparently, such that the output stream on the receiver side is equal to the corresponding input stream on the transmitter side.

Figure K.1.1 shows a simple block diagram of a channel bonded system.

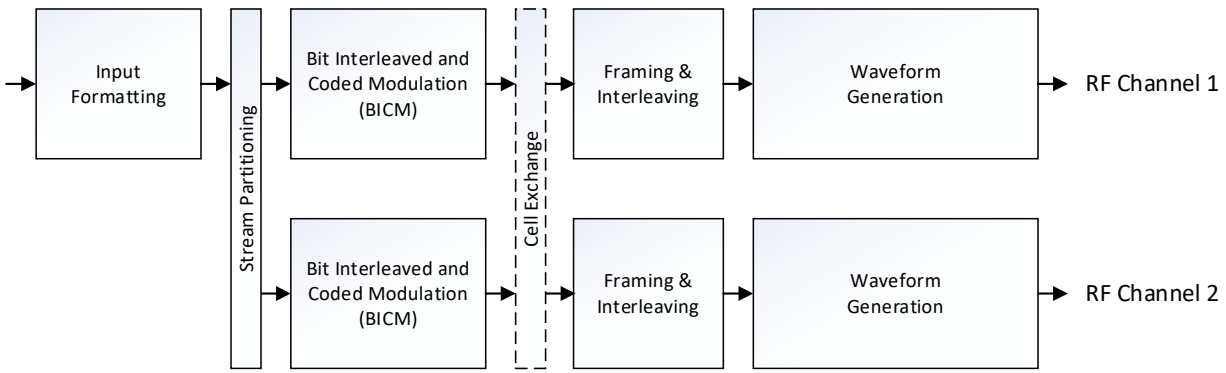


**Figure K.1.1** Simple block diagram of channel bonding.

All data packets of a PLP transmitted in channel bonding mode shall pass through a common input formatting block (i.e., utilizes same **L1D_plp_id** value on all RF channels), where the Baseband Header of the Baseband Packet is inserted. **L1D_rf_id** can be used in combination with **L1D_plp_id** to uniquely identify the partitioned stream for each RF channel. When channel bonding is used, the Baseband Header extension **counter** shall always be used (see Section 5.2.2.3.1 for details). This allows for correct reordering of the packets from different RF channels at the receiver side even in the presence of different delays on each RF channel. The ordering of Baseband Packets shall be maintained. At the output of the stream partitioning block, the Baseband Packets of the bonded PLP for each of the two partitioned streams shall be FEC encoded, bit-interleaved and modulated individually and transmitted on different RF channels. The use of channel bonding does not depend on the cell multiplexing method, channel bonding may be used with any valid multiplexing method, including LDM.

Since there are two BICM chains used in channel bonding, the total required TI memory will be twice that of a single chain.

Figure K.1.2 shows the transmitter side processing for channel bonding, with the joint input formatting stage showing Baseband Header insertion followed by stream partitioning.

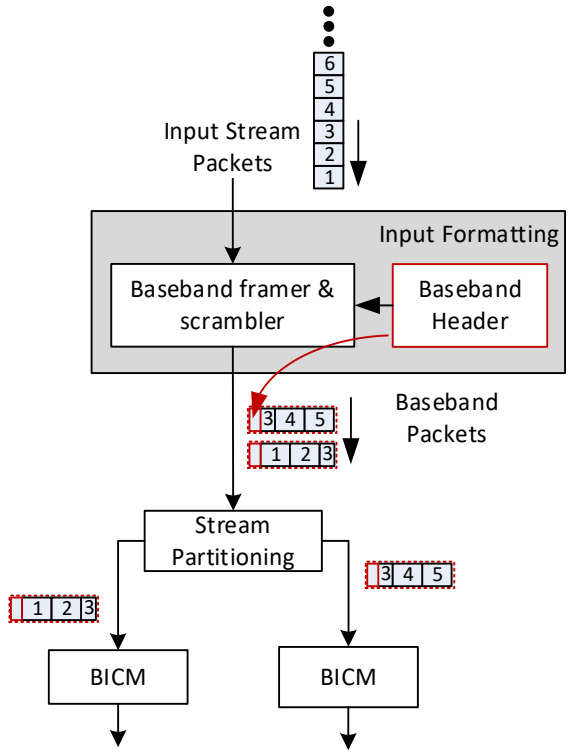


**Figure K.1.2** Transmitter side processing for channel bonding.

Channel bonding is possible in two operation modes, which can be selected by **L1D_plp_channel_bonding_format** as described in Table 9.23. The first mode is Plain Channel Bonding and is described in Section K.2, the second is Channel Bonding with SNR Averaging and is described in Section K.3.

## K.2 PLAIN CHANNEL BONDING

For plain channel bonding, the cell exchange stage in Figure K.3.1 shall be disabled, that is the two transmitter chains shall operate without any interaction after stream partitioning.

For plain channel bonding, each RF channel may use different parameter settings such as bandwidth, modulation, coding, FFT, guard interval length, and so on. Each RF channel is effectively handled as a standalone signal.

When bonded RF channels are configured with different BICM parameters for a channel-bonded PLP, the Baseband Packets for that channel-bonded PLP may have a different length on each of those bonded RF channels. When creating a Baseband Packet for a channel-bonded PLP, the Input Formatting block shall use the Baseband Packet length corresponding to the channel-bonded PLP's BICM parameters for the RF channel over which that Baseband Packet will be processed and transmitted.

In order to limit the memory size of the reconstruction circuit at the receiver side, load balancing is applied in the stream partitioner for plain channel bonding: The Baseband Packets shall be assigned to the two different modulation and encoding chains of the RF channel in

proportion to their respective PLP rates. For example if the same PLP rate is used in the two RF channels, Baseband Packets are equally split between the two RF channels. Note that PLP rate refers to uncoded PLP payload bitrate, i.e. the net data rate before Baseband Packet Header insertion and FEC encoding.

In addition, no more than 5 consecutive Baseband Packets shall be allocated to the same RF channel.

As an example this mode can be used for different robustness levels across two RF channels to compensate for differing propagation characteristics, for example on one VHF and one UHF channel.

## K.3 CHANNEL BONDING WITH SNR AVERAGING

When channel bonding with SNR averaging is used, the cell exchange block after the BICM stages shall be enabled. This bonding mode is intended to improve the PLP performance by increased diversity across the two RF channels.

For channel bonding with SNR averaging, the PLP rate on each RF path shall be the same. The stream partitioning block shall create Baseband Packets in an alternating way for the two BICM encoders.

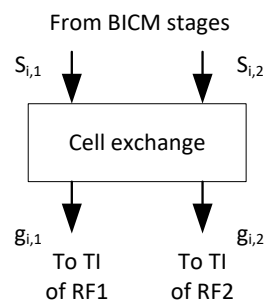


**Figure K.3.1** Cell exchange block.

The cell exchange shall be applied on PLP level and shall multiply the vector including both cells for each input path at index $i$ ($i = 0 \ldots N_{cells}-1$) by a cell exchange matrix:

$$\begin{pmatrix} g_{i,1} \\ g_{i,2} \end{pmatrix} = \begin{pmatrix} 1 & 0 \\ 0 & 1 \end{pmatrix} \cdot \begin{pmatrix} s_{i,1} \\ s_{i,2} \end{pmatrix} \text{ for i even}$$

$$\begin{pmatrix} g_{i,1} \\ g_{i,2} \end{pmatrix} = \begin{pmatrix} 0 & 1 \\ 1 & 0 \end{pmatrix} \cdot \begin{pmatrix} s_{i,1} \\ s_{i,2} \end{pmatrix} \text{ for i odd,}$$

with, $s_{i,1}$ and $s_{i,2}$ defined as the input cells of the cell exchange and $g_{i,1}$ and $g_{i,2}$ defined as the output cells towards the time interleavers of the RF channels RF 1 and RF 2. RF 1 and RF 2 shall be used as listed by the parameter **L1D_rf_id** in the RF frequency loop of the L1-Detail signaling.

As a result, every second cell of each channel-bonded BICM encoder is sent to the other transmitter signal. This provides SNR averaging across the two RF channels used and results in an overall improved decoding performance of channel bonded PLPs, due to increased diversity.

To enable low-complexity cell re-exchange on the receiver side, the framing of both RF channels shall be synchronized. This includes time synchronicity for bootstrap, Preamble, same OFDM waveform parameters as well as the same scheduling of the PLP in the payload frame. In

this mode, the PLP of each RF channel shall use the same ModCod setting, same Inner Code and Outer Code, number of FEC Blocks per subframe as well as TI mode and configuration.

# *Annex L*: MIMO

## L.1 OVERVIEW

MIMO (Multiple-Input Multiple-Output) improves robustness via additional spatial diversity and/or increases capacity by sending two data streams in a single RF channel (spatial multiplexing). The spatial multiplexing gain is achieved only in the case of MIMO, and allows overcoming the capacity limit of single antenna wireless communications in a given channel bandwidth without increasing the total transmission power. For SIMO (Single-Input Multiple-Output) and MISO (Multiple-Input Single-Output) only the spatial diversity gain is achieved. MIMO is an optional technology but when adopted shall conform to the requirements of this Annex.

In this version of the specification, MIMO processing is restricted to a 2×2 antenna system. This means that at least two antenna aerials are present at both transmitter and receiver side. In practice, cross-polarized MIMO (i.e., horizontal and vertical polarization) should be used. The transmitter should include individually-fed cross-polar antennas, and the receiver should include a cross-polar pair of antennas in order to receive and decode the MIMO signal.

Figure L.1.1 depicts the MIMO transmission chain. Two new blocks can be identified: MIMO demultiplexer and MIMO Precoding block. The MIMO transmission chain re-uses as many blocks as possible from SISO, including FEC codes, bit interleavers, constellations and frequency and time interleavers. Additional pilot patterns have been defined for MIMO such that the same echo tolerance/Doppler performance as for SISO is achieved. All blocks not specifically mentioned in this Annex, such as the input formatting, inverse Fast Fourier transform, guard interval, etc. shall follow the specification for SISO.

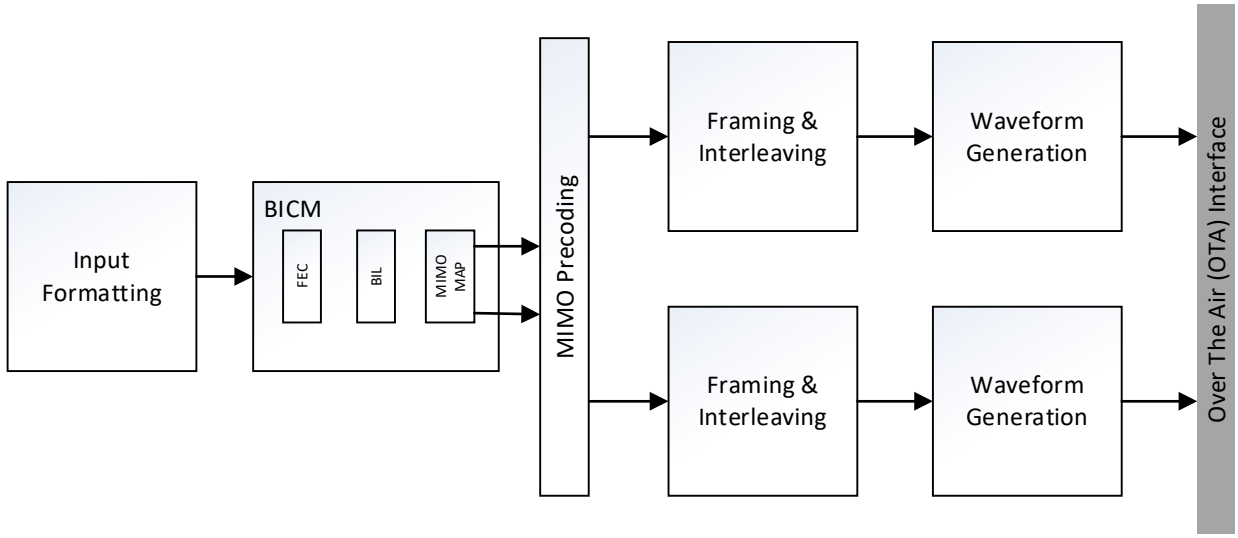


**Figure L.1.1** MIMO block diagram.

The MIMO MAP consists of a DeMultiplexer block followed by bit-to-IQ-mapping blocks. A block diagram of the MIMO MAP is shown in Figure L.1.2.

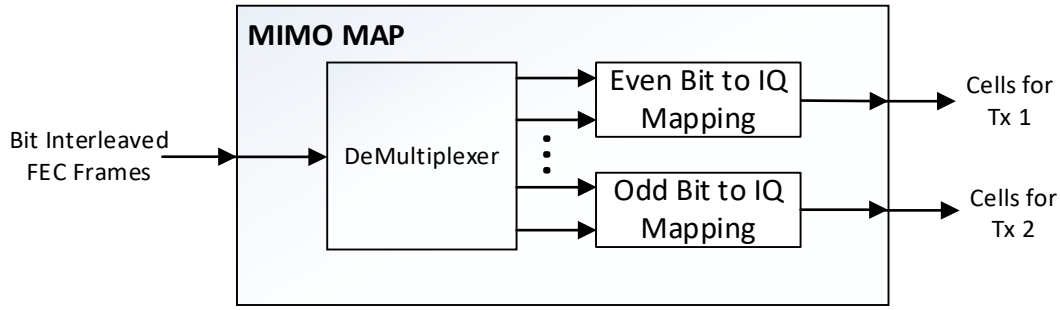


**Figure L.1.2** MIMO MAP block diagram.

MIMO processing shall not be applied to the Bootstrap or Preamble. MIMO processing shall only be applied to the data path. MIMO shall not be applied to signaling elements.

MIMO shall not be used with ACE nor LDM nor Channel Bonding, however the remaining features of the specification are compatible with MIMO.

## L.2 FEC CODING

The same FEC codes as in Section 6.1 shall be used for MIMO.

## L.3 BIT INTERLEAVING

The same bit interleavers as in Section 6.2 shall be used for MIMO.

## L.4 MIMO MAPPING

### L.4.1 Demultiplexer

The MIMO demultiplexer is composed of two stages. The first stage is exactly the same as the SISO demultiplexing described in Section 6.3.3. The second stage evenly spreads the output vectors of the first stage SISO demultiplexer into two constellation mappers, one for each transmit antenna.

At the second stage, the even vector ($y_{0,2n}$, ..., $y_{\eta MOD-1,2n}$) and the odd vector ($y_{0,2n+1}$, ..., $y_{\eta MOD-1,2n+1}$) are input to the mapper of transmit antenna #1 and #2 respectively, where $n$ is the value for indexing each vector:

$$n = (0, 1, 2, \ldots, N-1), \qquad N = \left\lfloor \frac{N_{cell}}{2} \right\rfloor$$

$N_{cell}$ is the number of the output data cells for each FEC Frame input to the demultiplexer, as shown in Table 6.14.

### L.4.2 Constellations

The same constellations as in Section 6.3 shall be used for MIMO. The same modulation order shall be transmitted from both antennas.

The combination of 256QAM and FEC codes with length $N_{inner}$=16200 bits shall not be allowed, since it does not yield an integer number of modulated cells per antenna per FEC Block. All remaining ModCod combinations are feasible for MIMO.

For MIMO L1 signaling does not signal the modulation order as for SISO but the bits per cell unit (bpcu), which defines the overall spectrum efficiency per cell for the two antennas, as shown in Table L.4.1.

**Table L.4.1** Bits Per Cell Unit and Modulation for MIMO

| Bits per Cell Unit (bpcu) | MIMO Modulation | |
|---|---|---|
| 4 | Tx1 | QPSK |
| | Tx2 | QPSK |
| 8 | Tx1 | 16QAM |
| | Tx2 | 16QAM |
| 12 | Tx1 | 64QAM |
| | Tx2 | 64QAM |
| 16 | Tx1 | 256QAM |
| | Tx2 | 256QAM |
| 20 | Tx1 | 1024QAM |
| | Tx2 | 1024QAM |
| 24 | Tx1 | 4096QAM |
| | Tx2 | 4096QAM |

### L.4.3 Constellation Superposition for LDM

The use of constellation superposition for LDM with MIMO is not defined in this version of the specification.

## L.5 PRECODING

MIMO precoding acts on a pair of input constellation symbols ($X_{2i}$, $X_{2i+1}$), where $i$ is the index of the cell pair within the FEC Block, and creates a pair of output constellation symbols as depicted in Figure L.5.1. Encoded cell pairs ($S_{2i}$, $S_{2i+1}$) shall be transmitted on the same OFDM symbol and carrier from transmit antenna #1 (Tx1) and transmit antenna #2 (Tx2), respectively.

MIMO precoding is never applied to the Bootstrap or the Preamble, only to data symbols.

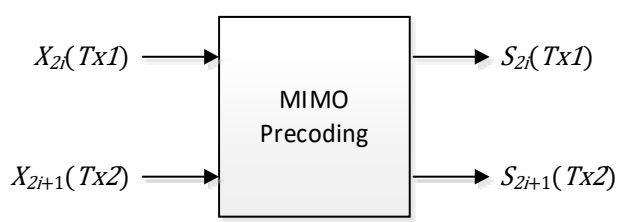


**Figure L.5.1** Generic MIMO Precoding block diagram.

MIMO precoding is based on spatial multiplexing, and consists of three different steps, as depicted in Figure L.5.2:

- Stream combining
- IQ polarization interleaving
- Phase hopping

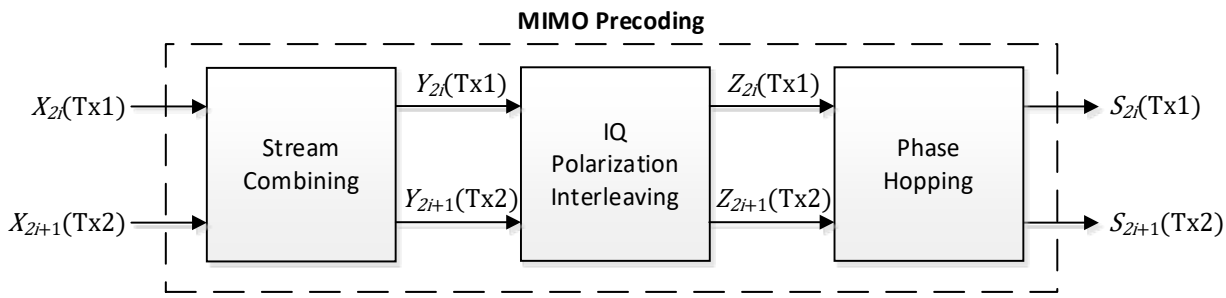


**Figure L.5.2** Detailed MIMO precoding block diagram.

MIMO precoding shall be applied at the PLP level. Each of the three sub-blocks of MIMO precoding is optional. This allows for the possibility of configuring the precoder in a transparent way in the transmission chain, such that the output pair of cells is exactly the input pair of cells. This particular case is known as plain spatial multiplexing.

$$S_{2i}(\text{Tx1}) = Z_{2i}(\text{Tx1}) = Y_{2i}(\text{Tx1}) = X_{2i}(\text{Tx1})$$

$$S_{2i+1}(\text{Tx2}) = Z_{2i+1}(\text{Tx2}) = Y_{2i+1}(\text{Tx2}) = X_{2i+1}(\text{Tx2})$$

The next subsections describe the signal processing performed at each sub-block of the precoding when used. If not used, the output pair of cells shall be exactly the same as the input pair of cells.

### L.5.1 Stream Combining

The stream combining consists of a combination of the pair of input constellation symbols based on a rotation matrix with angle $\theta$. The value of the rotation angle is fixed and its value depends on the modulation and coding used in the PLP. The stream combining operation shall be mathematically expressed as follows:

$$\begin{bmatrix} Y_{2i}(\text{Tx1}) \\ Y_{2i+1}(\text{Tx2}) \end{bmatrix} = \begin{bmatrix} \cos\theta & \sin\theta \\ \sin\theta & -\cos\theta \end{bmatrix} \begin{bmatrix} X_{2i}(\text{Tx1}) \\ X_{2i+1}(\text{Tx2}) \end{bmatrix}$$

Table L.5.1 defines the value of the rotation angle $\theta$ for each modulation order and code rate.

**Table L.5.1** Rotation Angle for the Stream Combining

| MIMO Code Rate | MIMO Modulation Order | | | | | |
|---|---|---|---|---|---|---|
| | 4bpcu (QPSK pairs) | 8bpcu (16QAM pairs) | 12bpcu (64QAM pairs) | 16bpcu (256QAM pairs) | 20bpcu (1kQAM \|pairs) | 24bpcu (4kQAM pairs) |
| 2/15 | 0° | 0° | 0° | 0° | 0° | 0° |
| 3/15 | 0° | 0° | 0° | 0° | 0° | 0° |
| 4/15 | 0° | 0° | 0° | 0° | 0° | 0° |
| 5/15 | 0° | 0° | 0° | 0° | 0° | 0° |
| 6/15 | 5° | 0° | 0° | 0° | 0° | 0° |
| 7/15 | 5° | 0° | 0° | 0° | 0° | 0° |
| 8/15 | 20° | 0° | 0° | 0° | 0° | 0° |
| 9/15 | 20° | 0° | 0° | 0° | 0° | 0° |
| 10/15 | 35° | 0° | 0° | 0° | 0° | 0° |
| 11/15 | 35° | 5° | 0° | 0° | 0° | 0° |
| 12/15 | 35° | 5° | 0° | 0° | 0° | 0° |
| 13/15 | 45° | 5° | 0° | 0° | 0° | 0° |

### L.5.2 I/Q Polarization Interleaving

The I/Q polarization interleaver is simply a switching interleaving operation, such that the output cells consist of the real (In-phase) component of one input symbol and the imaginary (Quadrature) component of the other input symbol. The I/Q polarization interleaving shall be described by the following equations:

$$Z_{2i}(\mathrm{Tx1}) = \mathrm{Re}\{Y_{2i}(\mathrm{Tx1})\} + j \cdot \mathrm{Im}\{Y_{2i+1}(\mathrm{Tx2})\}$$

$$Z_{2i+1}(\mathrm{Tx2}) = \mathrm{Re}\{Y_{2i+1}(\mathrm{Tx2})\} + j \cdot \mathrm{Im}\{Y_{2i}(\mathrm{Tx1})\}$$

### L.5.3 Phase Hopping

The phase hopping consists of a phase rotation to the symbols of the second transmit antenna. The phase hopping operation shall be mathematically expressed as follows:

$$\begin{bmatrix} S_{2i}(Tx1) \\ S_{2i+1}(Tx2) \end{bmatrix} = \begin{bmatrix} 1 & 0 \\ 0 & e^{j\phi(i)} \end{bmatrix} \begin{bmatrix} Z_{2i}(Tx1) \\ Z_{2i+1}(Tx2) \end{bmatrix}$$

where $\phi$ is the phase rotation angle, defined by the following equation:

$$\phi(i) = \frac{2\pi}{N} i, (N = 9), i = 0, \ldots, \frac{N_{cells}}{2} - 1$$

where $N_{cells}$ is the number of cells per FEC Block. The phase rotation is initialized to 0 radians at the beginning of each FEC Block and is incremented by 2π/9 for every cell pair.

## L.6 TIME INTERLEAVER

The same time interleavers as in Section 7.1 shall be used for MIMO. Since the time interleaving is carried out after the generation of two MIMO streams there are two parallel time interleavers. The time interleaving applied to both MIMO streams shall be identical. The total memory

requirement as described in Section 7.1.2 applies for each time interleaver of each antenna. Hence, time interleaving for MIMO requires twice the memory as for SISO.

## L.7 FRAMER

MIMO frames shall be built according to Section 7.2.

The specific multiplexing techniques allowed for MIMO shall be the following:

- Time division multiplexing (TDM), as described in Section 7.2.7.3.
- Frequency division multiplexing (FDM), as described in Section 7.2.7.5.
- Time and frequency division multiplexing (TFDM), as described in Section 7.2.7.6.

The number of available data cells for cell multiplexing can be obtained from tables in Section 7.2.6. Equivalent SISO pilot patterns that have the same number and position as those of MIMO scattered pilot patterns shall be used for a table lookup. Equivalent SISO scattered pilot patterns are shown in Table L.9.2.

## L.8 FREQUENCY INTERLEAVING

The same frequency interleaver as in Section 7.3 shall be used for MIMO.

## L.9 PILOT PATTERNS

### L.9.1 Pilot Antenna Encoding

MIMO pilots fall on exactly the same positions as for SISO, but the amplitudes and/or phases of the scattered, continual, edge, and subframe boundary pilots may be modified compared to SISO. Two MIMO pilot antenna encoding algorithms are defined, namely:

- Walsh-Hadamard encoding.
- Null pilot encoding.

Only one MIMO pilot encoding algorithm shall be configured for a given frame.

Table L.9.1 gives an overview of the different types of pilots and the corresponding MIMO pilot encoding mechanism per antenna, where SISO indicates that the pilots are not modified compared to SISO, WH indicates Walsh-Hadamard encoding and NP indicates null pilot encoding. Both antennas shall transmit in all pilot positions, although the amplitudes of some transmitted pilots for null pilot encoding will be zero.

Note: Those cells which would be both an additional continual pilot and a scattered pilot shall be treated as scattered pilots, and they shall be encoded using Walsh-Hadamard encoding (for antenna #2) or using null pilot encoding (for both antennas) depending upon the configured MIMO pilot encoding algorithm. The additional continual pilots that do not fall on scattered-pilot-bearing cells shall be treated similarly to common continual pilots and shall not be modified compared to SISO.

**Table L.9.1** MIMO Pilot Antenna Encoding Overview

| Pilot Encoding Algorithm | Antenna | Scattered Pilot | Subframe Boundary Pilot | Common Continual Pilot | Additional Continual Pilot | Edge Pilot |
|---|---|---|---|---|---|---|
| Walsh-Hadamard | #1 | SISO | SISO | SISO | SISO | SISO |
| | #2 | WH | WH | SISO | SISO/WH | WH |
| Null Pilot | #1 | NP | SISO | SISO | SISO/NP | SISO |
| | #2 | NP | WH | SISO | SISO/NP | WH |

MIMO pilots are divided into two groups, namely group 1 and group 2, depending on the pilot encoding scheme used, as described in Section L.9.2. Both pilot groups are transmitted from each antenna. However, each pilot encoding algorithm applies a specific signal processing to each pilot group for each antenna.

### L.9.1.1. Walsh-Hadamard

With Walsh-Hadamard encoding, the phases of the scattered, additional continual, edge, and subframe boundary pilots for group 2 are inverted in the signal transmitted from antenna #2. The phases of both the group 1 and group 2 pilots transmitted from antenna #1 and of the group 1 pilots transmitted from antenna #2 shall not be modified.

The scattered pilots transmitted from antenna #2 shall be inverted compared to antenna #1 on alternate scattered-pilot-bearing carriers. These inverted scattered pilots represent the group 2 scattered pilots for antenna #2. Both group 1 and group 2 scattered pilots for antenna #2 shall be calculated using the following equations:

$$\mathrm{Re}\{c_{m,l,k}\} = 2 \cdot (-1)^{\frac{k}{D_X}} \cdot A_{\mathrm{SP}} \cdot (\frac{1}{2} - r_k)$$

$$\mathrm{Im}\{c_{m,l,k}\} = 0$$

Common continual pilots and additional continual pilots on non-scattered-pilot-bearing cells shall not be inverted for either transmit antenna. The few additional continual pilots which fall on scattered-pilot-bearing cells for which the scattered pilot transmitted from antenna #2 would be inverted shall be inverted. Both group 1 and group 2 additional continual pilots for antenna #2 shall be calculated using the following equations:

$$\mathrm{Re}\{c_{m,l,k}\} = 2 \cdot (-1)^{\frac{k}{D_X}} \cdot A_{\mathrm{SP}} \cdot (\tfrac{1}{2} - r_k) \qquad \text{for } k \bmod D_X = 0$$

$$\mathrm{Re}\{c_{m,l,k}\} = 2 \cdot A_{\mathrm{SP}} \cdot (\tfrac{1}{2} - r_k) \qquad \text{otherwise}$$

$$\mathrm{Im}\{c_{m,l,k}\} = 0$$

Note: Those cells which would be both an additional continual pilot and a scattered pilot are treated as scattered pilots as described above. All additional continual pilots shall have the amplitude $A_{\mathrm{SP}}$ as in SISO.

The edge pilots from antenna #2 shall be inverted compared to antenna #1 on odd-numbered OFDM symbols. Both group 1 and group 2 edge pilots for antenna #2 shall be calculated using the following equations:

$$\mathrm{Re}\{c_{m,l,k}\} = 2 \cdot (-1)^l \cdot A_{\mathrm{SP}} \cdot \left(\frac{1}{2} - r_k\right)$$

$$\mathrm{Im}\{c_{m,l,k}\} = 0$$

The subframe boundary pilots from antenna #2 shall be inverted compared to antenna #1 on alternate scattered-pilot-bearing carriers. Both group 1 and group 2 subframe boundary pilots for antenna #2 shall be calculated using the following equations:

$$\mathrm{Re}\{c_{m,l,k}\} = 2 \cdot (-1)^{\frac{k}{D_X}} \cdot A_{\mathrm{SP}} \cdot \left(\frac{1}{2} - r_k\right)$$

$$\mathrm{Im}\{c_{m,l,k}\} = 0$$

### L.9.1.2. Null Pilot

With null pilot encoding, the amplitudes of the scattered pilots of both group 1 and group 2 are modified in the signals transmitted from antennas #1 and #2. With null pilot encoding, antenna #1 shall transmit group 1 scattered pilots with 3 dB increased transmit power (amplitude of $\sqrt{2}A_{\mathrm{SP}}$) and group 2 scattered pilots with null power (zero amplitude). Similarly, antenna #2 shall transmit group 2 scattered pilots with 3 dB increased transmit power (amplitude of $\sqrt{2}A_{\mathrm{SP}}$) and group 1 scattered pilots with null power (zero amplitude).

Both group 1 and group 2 scattered pilots for antenna #1 shall be calculated using the following equations:

$$\mathrm{Re}\{c_{m,l,k}\} = \sqrt{2} \cdot \left(1 + (-1)^{\frac{k}{D_X D_Y} + \frac{(D_Y - 1)l}{D_Y}}\right) \cdot A_{\mathrm{SP}} \cdot (\frac{1}{2} - r_k)$$

$$\mathrm{Im}\{c_{m,l,k}\} = 0$$

The scattered pilots transmitted from antenna #2 shall be as given in the following equations:

$$\mathrm{Re}\{c_{m,l,k}\} = \sqrt{2} \cdot \left(1 + (-1)^{\frac{k}{D_X D_Y} + \frac{(D_Y - 1)l}{D_Y} + 1}\right) \cdot A_{\mathrm{SP}} \cdot (\frac{1}{2} - r_k)$$

$$\mathrm{Im}\{c_{m,l,k}\} = 0$$

Common continual pilots and additional continual pilots on non-scattered-pilot-bearing cells shall not be modified compared to SISO for either transmit antenna. The few additional continual pilots falling on scattered-pilot-bearing carriers shall be encoded using the null pilot encoding for scattered pilots.

Note: Those cells which would be both an additional continual pilot and a scattered pilot shall be treated as scattered pilots and therefore shall have the amplitude $\sqrt{2}A_{\mathrm{SP}}$ or 0. The additional continual pilot cells which do not fall on scattered pilot positions shall have the amplitude $A_{\mathrm{SP}}$ as in SISO.

With null pilot encoding, the edge pilots and subframe boundary pilots shall be encoded using Walsh-Hadamard encoding. The phases of the group 2 edge and subframe boundary pilots shall be inverted in the signal transmitted from antenna #2 using Walsh-Hadamard encoding as described in the previous section.

### L.9.2 Pilot Schemes

This section illustrates the scattered pilot patterns for MIMO following the same model used for the SISO scattered pilot patterns in Annex E.

Twelve MIMO scattered pilot patterns are defined for Walsh-Hadamard pilot encoding and are illustrated from Figure L.9.1 to Figure L.9.12.Sixteen MIMO scattered pilot patterns are defined for null pilot encoding and are illustrated from Figure L.9.13 to Figure L.9.28.

The terminology employed for the MIMO pilot patterns is MP**a**_**b**, where **a** = $D_X$ and **b** = $D_Y$ are defined taking into account the two transmit antennas, such that each MIMO pilot pattern has pilots in exactly the same positions as the equivalent SISO pilot pattern.

Table L.9.2 lists each MIMO pilot scheme, the corresponding equivalent SISO pilot scheme, and the values of $D_X$ and $D_Y$. Note that the equivalent values of $D_X$ and $D_Y$ per transmit antenna for the two available MIMO pilot encoding schemes are not shown in the table. The last four rows of the table are only allowed for null pilot encoding.

**Table L.9.2** MIMO Pilot Schemes with Equivalent SISO Pilot Schemes and $D_X$ and $D_Y$ Values

| MIMO Pilot Scheme | Equivalent SISO Pilot Scheme | DX | DY |
|---|---|---|---|
| MP3_2 | SP3_2 | 3 | 2 |
| MP3_4 | SP3_4 | 3 | 4 |
| MP4_2 | SP4_2 | 4 | 2 |
| MP4_4 | SP4_4 | 4 | 4 |
| MP6_2 | SP6_2 | 6 | 2 |
| MP6_4 | SP6_4 | 6 | 4 |
| MP8_2 | SP8_2 | 8 | 2 |
| MP8_4 | SP8_4 | 8 | 4 |
| MP12_2 | SP12_2 | 12 | 2 |
| MP12_4 | SP12_4 | 12 | 4 |
| MP16_2 | SP16_2 | 16 | 2 |
| MP16_4 | SP16_4 | 16 | 4 |
| MP24_2 | SP24_2 | 24 | 2 |
| MP24_4 | SP24_4 | 24 | 4 |
| MP32_2 | SP32_2 | 32 | 2 |
| MP32_4 | SP32_4 | 32 | 4 |

Similar restrictions for the MIMO pilot schemes in terms of the FFT size and the GI length apply as for SISO, as described in Table 8.3. The allowed FFT size and GI length combinations with Walsh-Hadamard encoding shall be as defined in Table L.9.3. The allowed FFT size and GI length combinations with null pilot encoding shall be as defined in Table_L.9.4. *N/A* indicates a combination of FFT size and GI length that has no valid scattered pilot pattern.

**Table L.9.3** Allowed Scattered Pilot Patterns for Each Allowed Combination of FFT Size and Guard Interval Length in MIMO Mode with Walsh-Hadamard Encoding

| GI Pattern | Samples | 8K FFT | 16K FFT | 32K FFT |
|---|---|---|---|---|
| GI1_192 | 192 | MP16_2, MP16_4, MP8_2, MP8_4 | MP16_2, MP16_4 | MP16_2 |
| GI2_384 | 384 | MP8_2, MP8_4, MP4_2, MP4_4 | MP16_2, MP16_4, MP8_2, MP8_4 | MP16_2 |
| GI3_512 | 512 | MP6_2, MP6_4, MP3_2, MP3_4 | MP12_2, M12_4, MP6_2, MP6_4 | MP12_2 |
| GI4_768 | 768 | MP4_2, MP4_4 | M8_2, M8_4, MP4_2, MP4_4 | MP16_2, MP8_2 |
| GI5_1024 | 1024 | MP3_2, MP3_4 | MP6_2, MP6_4, MP3_2, MP3_4 | MP12_2, MP6_2 |
| GI6_1536 | 1536 | N/A | MP4_2, MP4_4 | MP8_2, MP4_2 |
| GI7_2048 | 2048 | N/A | MP3_2, MP3_4 | MP6_2, MP3_2 |
| GI8_2432 | 2432 | N/A | MP3_2, MP3_4 | MP6_2, MP3_2 |
| GI9_3072 | 3072 | N/A | N/A | MP3_2 |
| GI10_3648 | 3648 | N/A | N/A | MP3_2 |
| GI11_4096 | 4096 | N/A | N/A | MP3_2 |
| GI12_4864 | 4864 | N/A | N/A | MP3_2 |

**Table_L.9.4** Allowed Scattered Pilot Patterns for Each Allowed Combination of FFT Size and Guard Interval Length in MIMO Mode with Null Pilot Encoding

| GI Pattern | Samples | 8K FFT | 16K FFT | 32K FFT |
|---|---|---|---|---|
| GI1_192 | 192 | MP32_2, MP32_4, MP16_2, MP16_4 | MP32_2, MP32_4 | MP32_2 |
| GI2_384 | 384 | MP16_2, MP16_4, MP8_2, MP8_4 | MP32_2, MP32_4, MP16_2, MP16_4 | MP32_2 |
| GI3_512 | 512 | MP12_2, MP12_4, MP6_2, MP6_4 | MP24_2, M24_4, MP12_2, MP12_4 | MP24_2 |
| GI4_768 | 768 | MP8_2, MP8_4, MP4_2, MP4_4 | M16_2, M16_4, MP8_2, MP8_4 | MP32_2, MP16_2 |
| GI5_1024 | 1024 | MP6_2, MP6_4, MP3_2, MP3_4 | MP12_2, MP12_4, MP6_2, MP6_4 | MP24_2, MP12_2 |
| GI6_1536 | 1536 | MP4_2, MP4_4 | MP8_2, MP8_4, MP4_2, MP4_4 | MP16_2, MP8_2 |
| GI7_2048 | 2048 | MP3_2, MP3_4 | MP6_2, MP6_4, MP3_2, MP3_4 | MP12_2, MP6_2 |
| GI8_2432 | 2432 | N/A | MP6_2, MP6_4, MP3_2, MP3_4 | MP12_2, MP6_2 |
| GI9_3072 | 3072 | N/A | MP4_2, MP4_4 | MP8_2, MP3_2 |
| GI10_3648 | 3648 | N/A | MP4_2, MP4_4 | MP8_2, MP3_2 |
| GI11_4096 | 4096 | N/A | MP3_2, MP3_4 | MP6_2, MP3_2 |
| GI12_4864 | 4864 | N/A | N/A | MP6_2, MP3_2 |

### L.9.2.1. Walsh-Hadamard

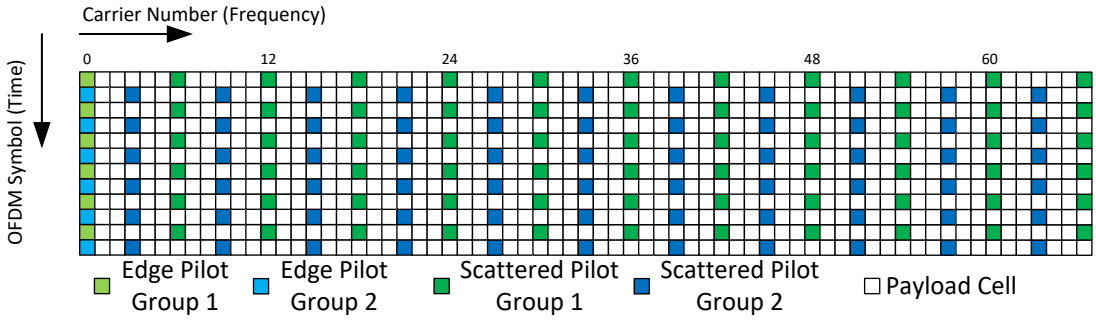


**Figure L.9.1** MIMO pilot scheme MP3_2 for Walsh-Hadamard pilot encoding.

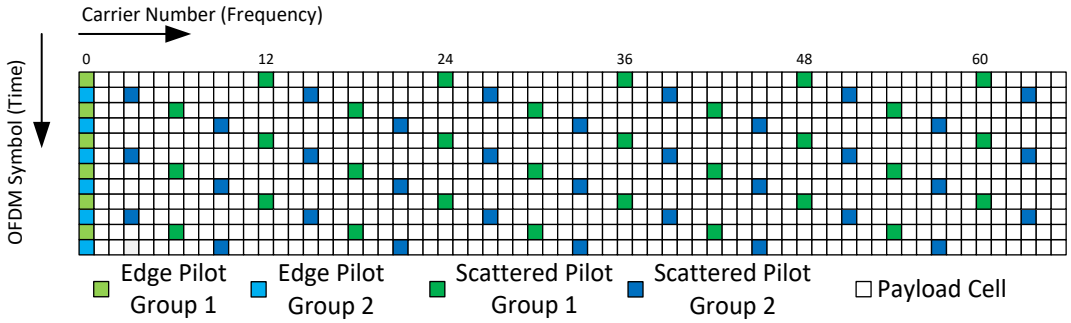


**Figure L.9.2** MIMO pilot scheme MP3_4 for Walsh-Hadamard pilot encoding.

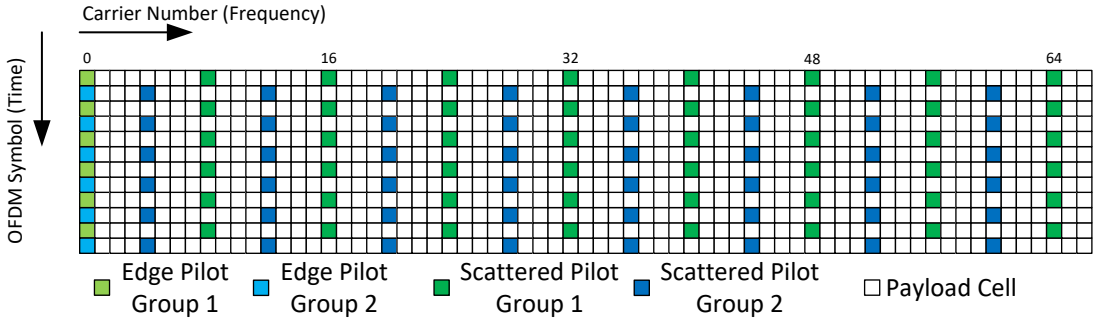


**Figure L.9.3** MIMO pilot scheme MP4_2 for Walsh-Hadamard pilot encoding.

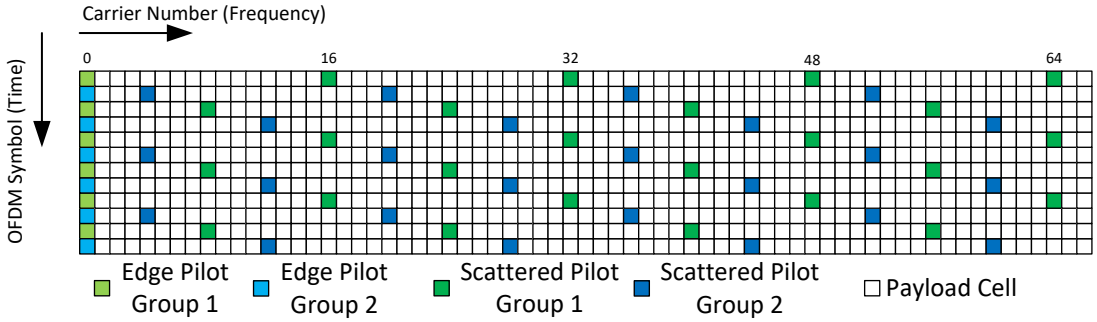


**Figure L.9.4** MIMO pilot scheme MP4_4 for Walsh-Hadamard pilot encoding.

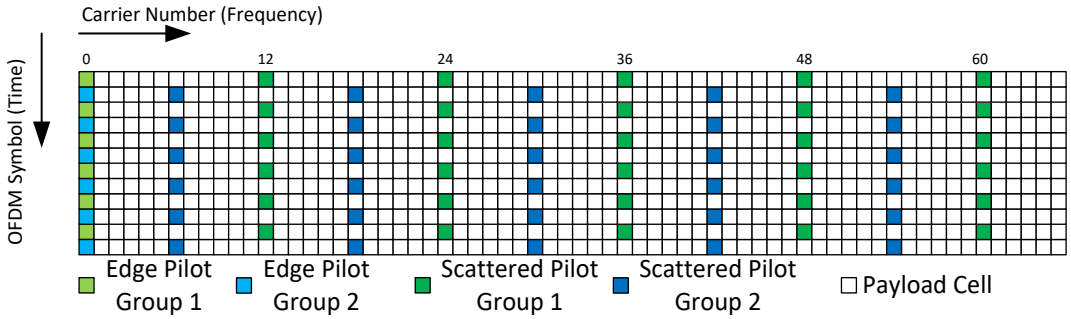


**Figure L.9.5** MIMO pilot scheme MP6_2 for Walsh-Hadamard pilot encoding.

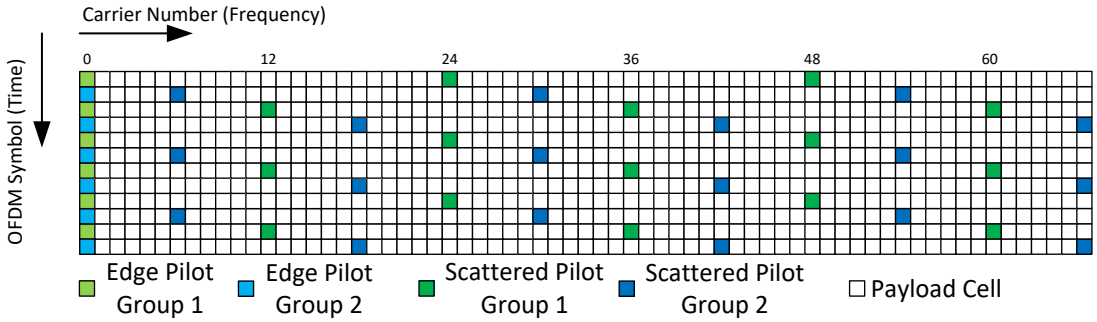


**Figure L.9.6** MIMO pilot scheme MP6_4 for Walsh-Hadamard pilot encoding.

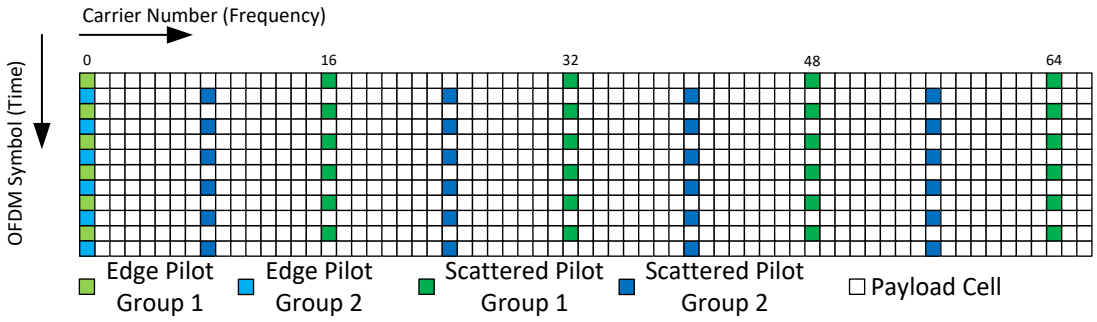


**Figure L.9.7** MIMO pilot scheme MP8_2 for Walsh-Hadamard pilot encoding.

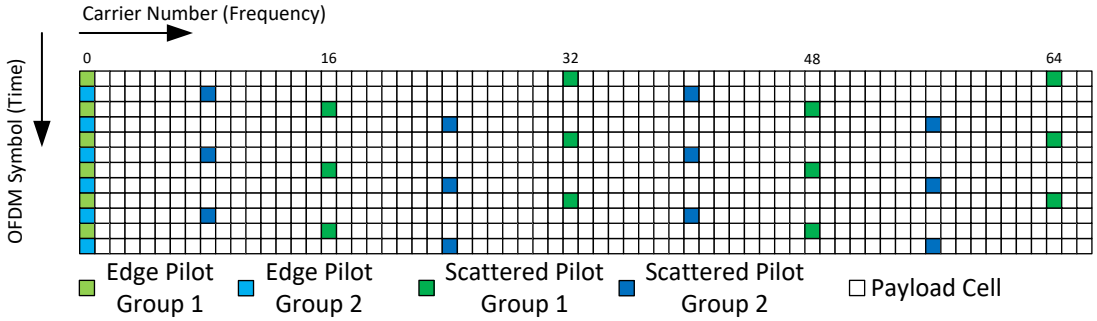


**Figure L.9.8** MIMO pilot scheme MP8_4 for Walsh-Hadamard pilot encoding.

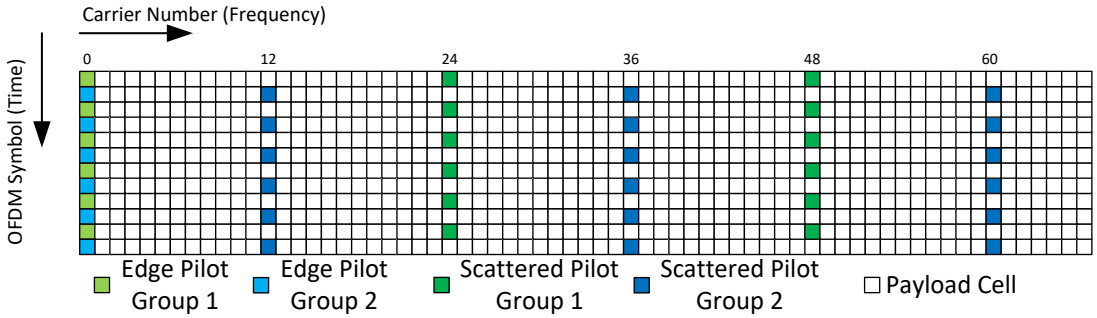


**Figure L.9.9** MIMO pilot scheme MP12_2 for Walsh-Hadamard pilot encoding.

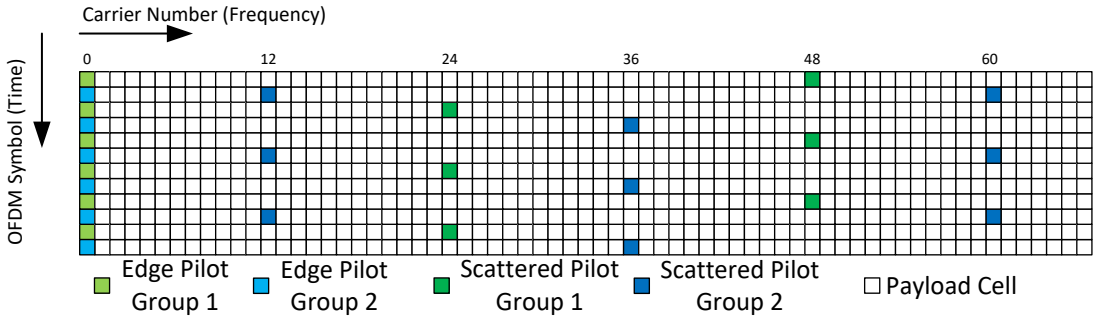


**Figure L.9.10** MIMO pilot scheme MP12_4 for Walsh-Hadamard pilot encoding.

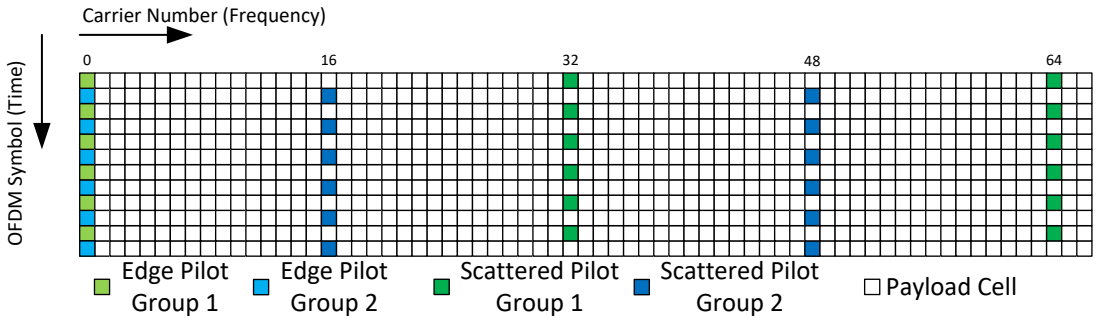


**Figure L.9.11** MIMO pilot scheme MP16_2 for Walsh-Hadamard pilot encoding.

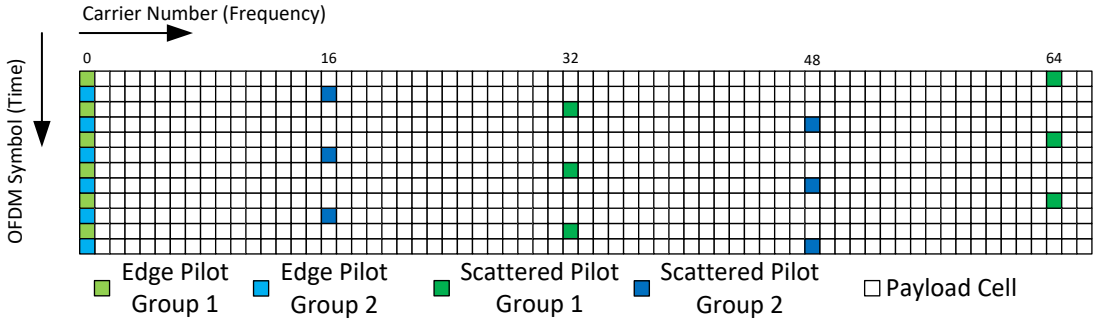


**Figure L.9.12** MIMO pilot scheme MP16_4 for Walsh-Hadamard pilot encoding.

### L.9.2.2. Null Pilots

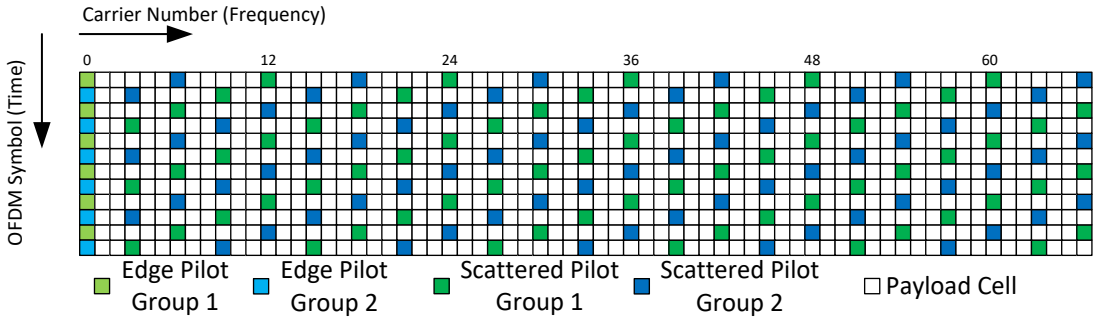


**Figure L.9.13** MIMO pilot scheme MP3_2 for null pilot encoding.

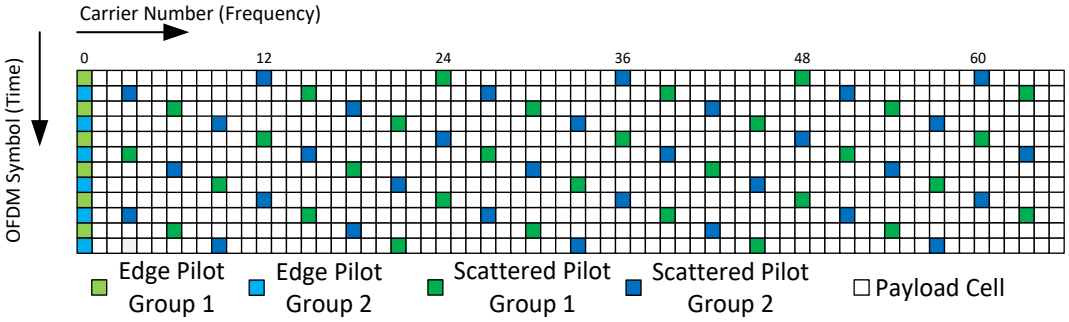


**Figure L.9.14** MIMO pilot scheme MP3_4 for null pilot encoding.

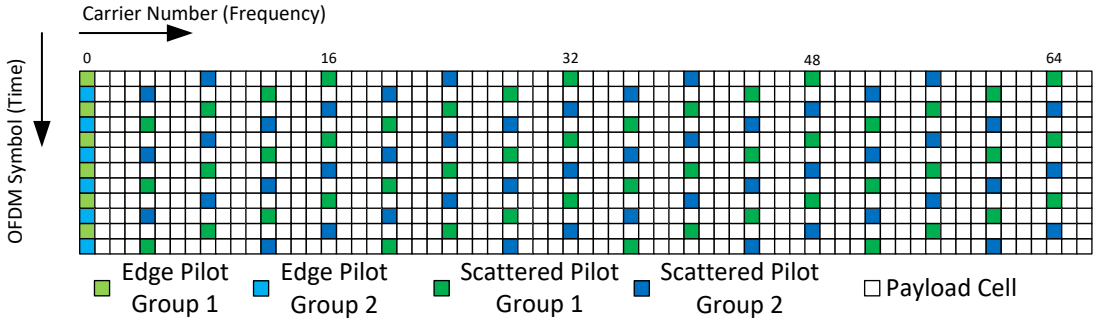


**Figure L.9.15** MIMO pilot scheme MP4_2 for null pilot encoding.

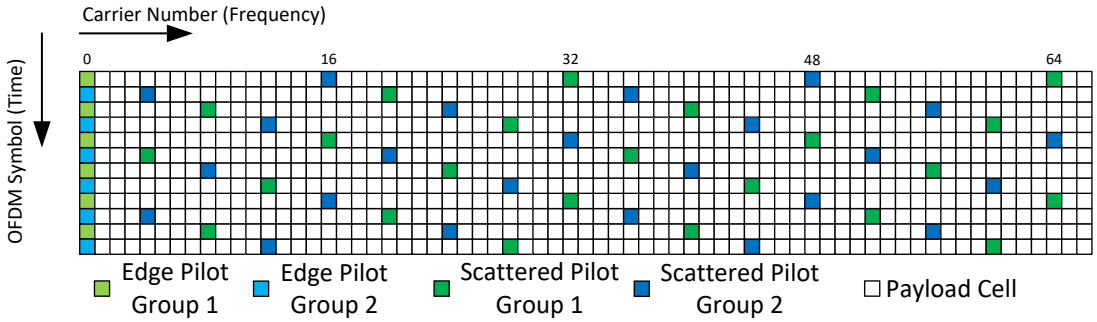


**Figure L.9.16** MIMO pilot scheme MP4_4 for null pilot encoding.

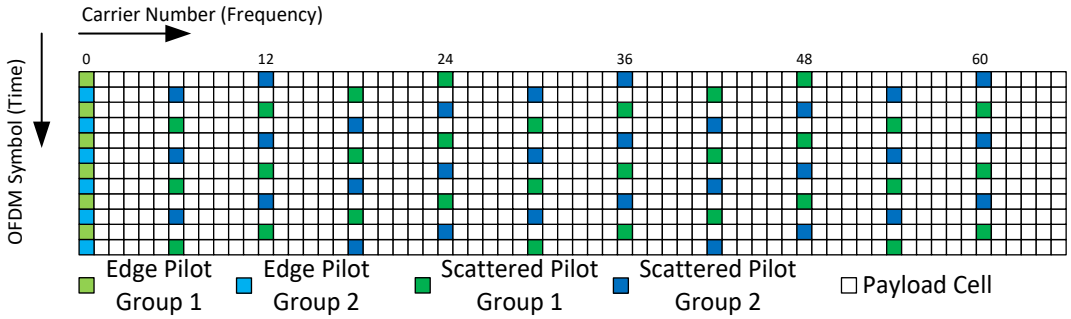


**Figure L.9.17** MIMO pilot scheme MP6_2 for null pilot encoding.

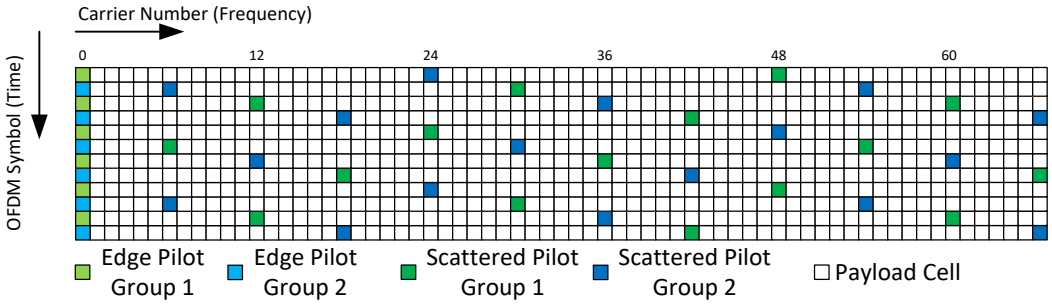


**Figure L.9.18** MIMO pilot scheme MP6_4 for null pilot encoding.

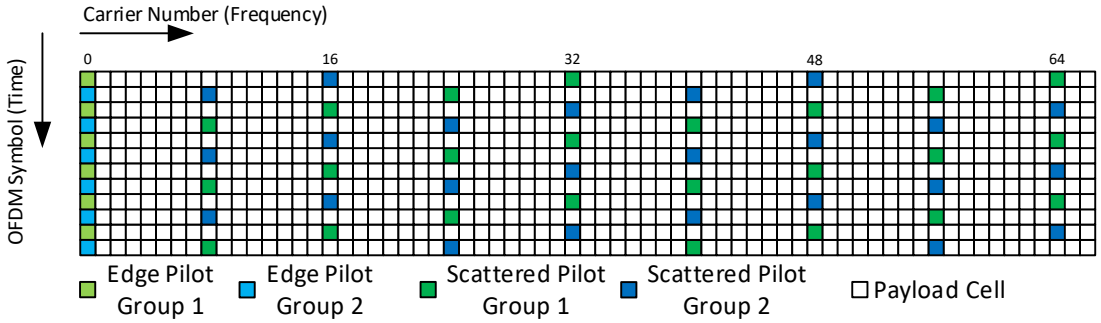


**Figure L.9.19** MIMO pilot scheme MP8_2 for null pilot encoding.

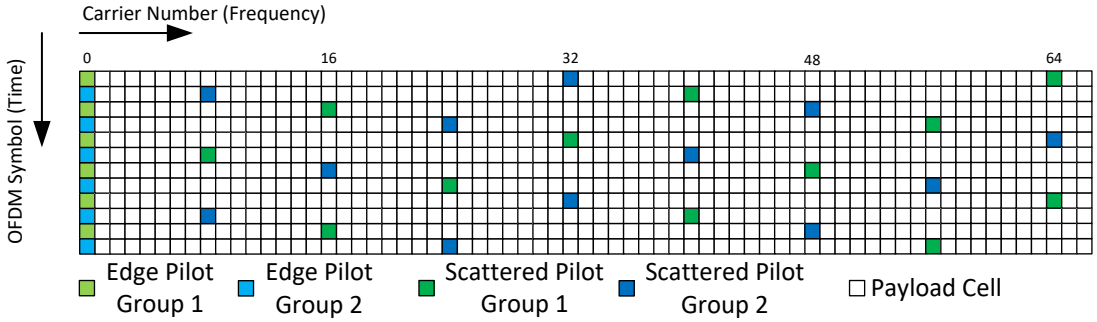


**Figure L.9.20** MIMO pilot scheme MP8_4 for null pilot encoding.

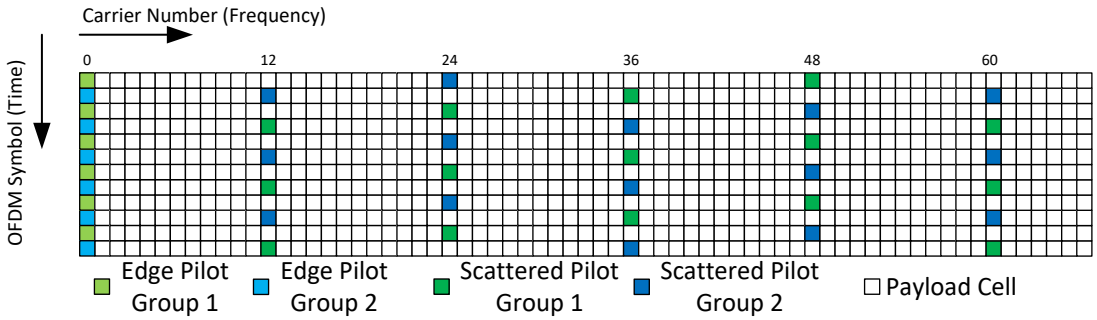


**Figure L.9.21** MIMO pilot scheme MP12_2 for null pilot encoding.

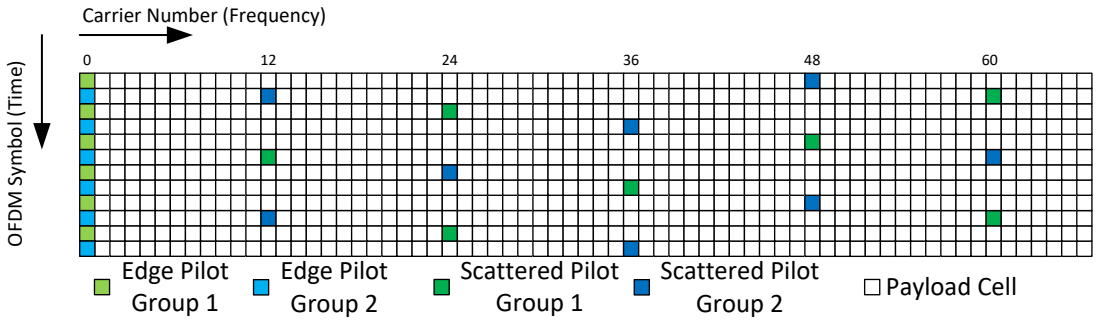


**Figure L.9.22** MIMO pilot scheme MP12_4 for null pilot encoding.

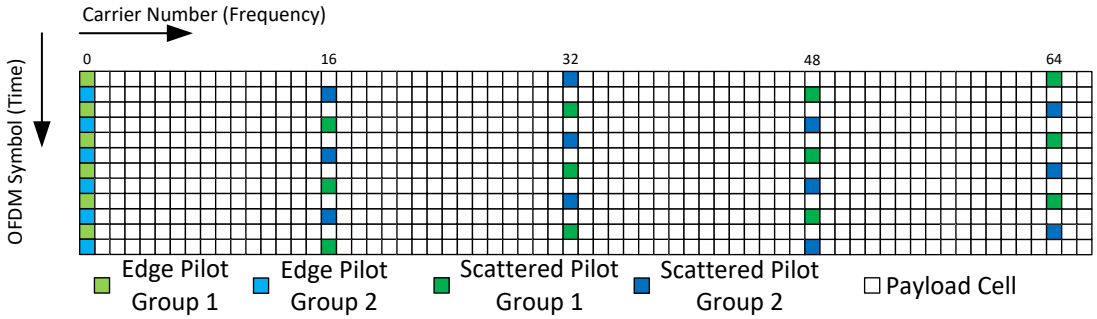


**Figure L.9.23** MIMO pilot scheme MP16_2 for null pilot encoding.

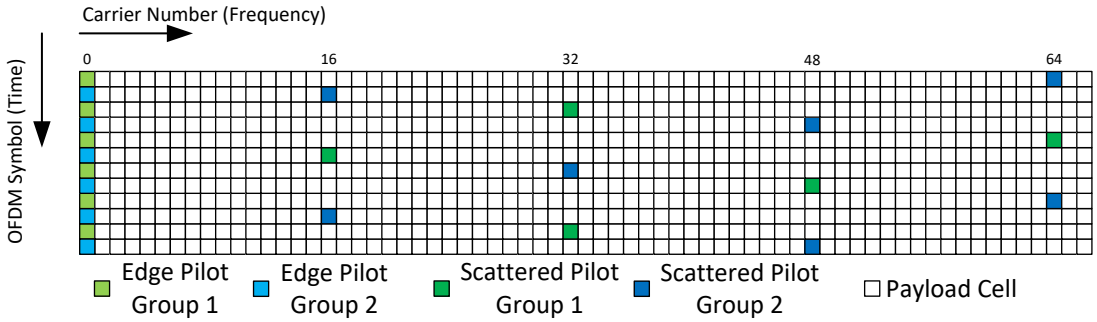


**Figure L.9.24** MIMO pilot scheme MP16_4 for null pilot encoding.

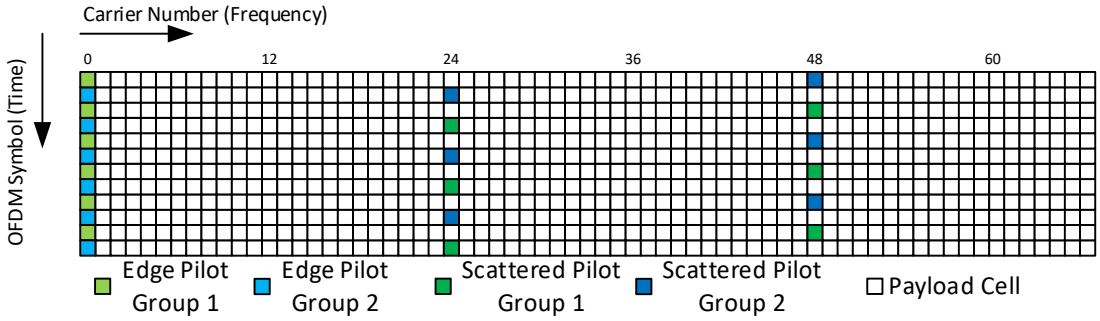


**Figure L.9.25** MIMO pilot scheme MP24_2 for null pilot encoding.

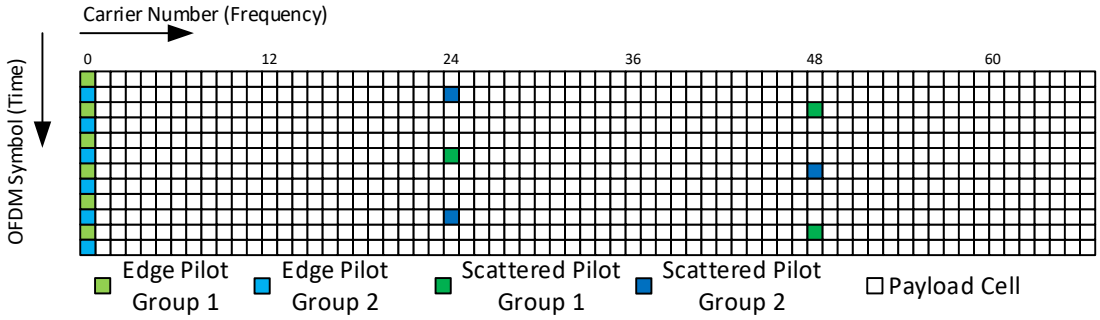


**Figure L.9.26** MIMO pilot scheme MP24_4 for null pilot encoding.

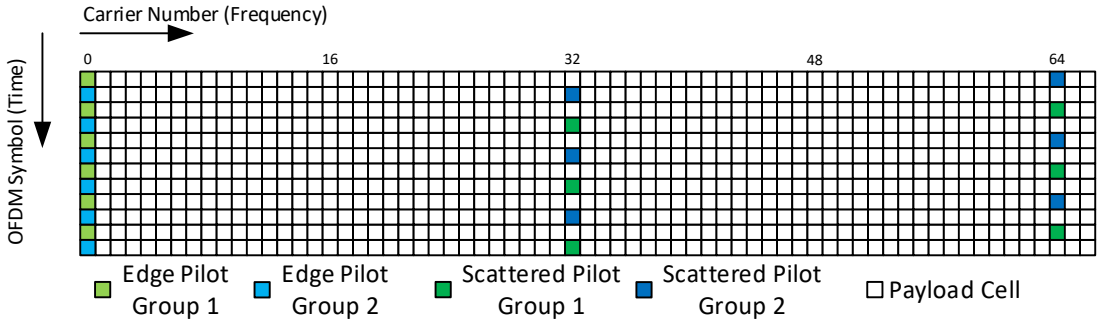


**Figure L.9.27** MIMO pilot scheme MP32_2 for null pilot encoding.

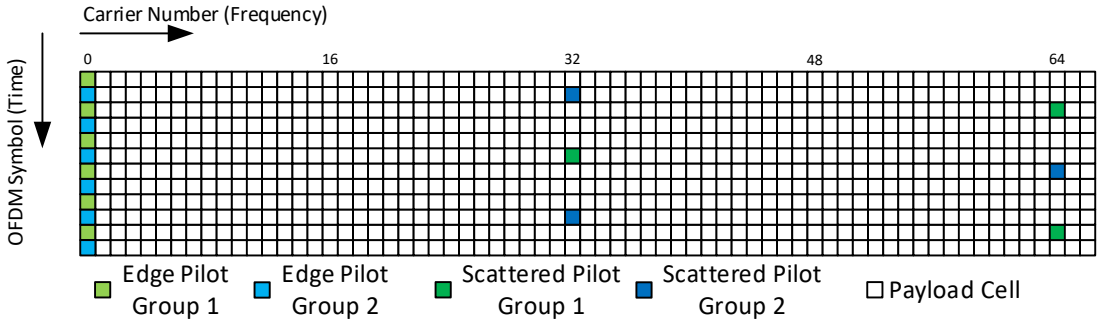


**Figure L.9.28** MIMO pilot scheme MP32_4 for null pilot encoding.

## L.10 MISO

The use of MISO, as described in Section 8.2 may be optionally added to MIMO with a unique MISO code applied per station or per antenna.

## L.11 PAPR REDUCTION

The Tone Reservation Peak to Average Power Ratio reduction technique, as described in Section 8.4.1, may be used with MIMO. The Active Constellation Extension (ACE) technique, as described in Section 8.4.2, shall not be used with MIMO.

## L.12 CHANNEL BONDING

The use of Channel Bonding with MIMO is not defined in this version of the specification, and Channel Bonding shall not be used together with MIMO.

## L.13 L1 SIGNALLING FOR MIMO

This section highlights the L1 signaling data specific to MIMO defined in Section 9.

The use of MIMO in the first subframe of the current frame is signaled in the Preamble with the L1-Basic parameter **L1B_first_sub_mimo**.

The use of MIMO in subframes after the first subframe of the current frame is signaled in the Preamble with the L1-Detail parameter **L1D_mimo**.

The configuration of the MIMO precoding is signaled with the L1-Detail parameters **L1D_plp_mimo_stream_combining**, **L1D_plp_mimo_IQ_interleaving**, and **L1D_plp_mimo_PH**.

The choice of the scattered pilot pattern for MIMO is signaled with the L1-Basic parameter **L1B_first_sub_scattered_pilot_pattern** if MIMO is used in the first subframe of the current frame, and

with the L1-Detail parameter **L1D_scattered_pilot_pattern** for subframes after the first subframe. These signaling parameters are also used for SISO but with a different interpretation.

The choice of the bits per cell use for MIMO is signaled with the L1-Detail parameter **L1D_plp_mod**. This signaling parameter is also used for SISO but with a different interpretation.

# *Annex M*: Example of Peak to Average Power Ratio Reduction Algorithms

## M.1 PAPR REDUCTION ALGORITHMS

The specific algorithms used to reduce peak to average power ratio are left to manufacturers to devise the most appropriate method for implementation on their equipment. For reference, Section M.2 outlines one algorithm for tone reservation (TR) and Section M.3 outlines a possible algorithm for the active constellation extension (ACE) method.

## M.2 TR ALGORITHM

The tone reservation method consists of reserving a set of carriers $N_{TR}$ to reduce the signal peaks.

The following definitions are used for the PAPR reduction algorithm description:

$n$ The sample index, $0 \le n < N_{FFT}$.

$i$ The iteration number of the TR algorithm.

$x_n$ The $n$-th sample of the complex baseband time-domain input to the TR algorithm.

$x'_n$ The $n$-th sample of the complex baseband time-domain output of the TR algorithm.

$c_n^{(i)}$ The $n$-th sample of the time-domain reduction signal in the $i$-th iteration of the TR algorithm.

$r_k^{(i)}$, The modulation value in the $i$-th iteration for the reserved tone whose carrier index is $k$.

$p_n$ The $n$-th sample of the reference kernel signal, defined by:

$$p_n = \frac{1}{N_{TR}} \sum_{k \in S_l} e^{j\frac{2\pi n(k-K_c)}{N_{FFT}}}$$

where $l$ is the OFDM symbol index and $S_l$ is the set of reserved carrier indices for symbol $l$, and $K_C = (K_{\max} + K_{\min})/2$ is the index $k$ of the center ("DC") carrier.

Note 1: The reference kernel corresponds to the inverse Fourier Transform of a ($N_{FFT}$, 1) vector $\mathbf{1}_{TR}$ having $N_{TR}$ elements of ones at the positions corresponding to the reserved carrier indices $k \in S_l$.

This PAPR reduction algorithm is described below.

**Initialization**:

The initial values for the peak reduction signal are set to zero:

$$c_n^{(0)} = 0, \quad 0 \le n < N_{FFT}$$

$$r_k^{(0)} = 0, k \in S_l$$

**Iteration:**

1) $i$ starts from 1.
2) Find the maximum magnitude of $x_n + c_n^{(i-1)}$, denoted by $y^{(i)}$, and the corresponding sample index, $m^{(i)}$ in the $i$-th iteration.

$$\begin{cases} y^{(i)} = \max_n \left| x_n + c_n^{(i-1)} \right| \\ m^{(i)} = \arg\max_n \left| x_n + c_n^{(i-1)} \right| \end{cases}, \qquad \text{for } n = 0,1,\ldots N_{FFT} - 1,$$

If $y^{(i)}$ is less than or equal to a desired clipping magnitude level, $V_{clip}$ then decrease $i$ by 1 and go to step 9.

3) Calculate a unit-magnitude phasor $u^{(i)}$ in the direction of the peak to be cancelled:

$$u^{(i)} = \frac{x_{m^{(i)}} + c_{m^{(i)}}^{(i-1)}}{y^{(i)}}$$

4) For each reserved tone, calculate the maximum magnitude of correction $\alpha_k^{(i)}$ that can be applied without causing the reserved carrier amplitude to exceed the maximum allowed value $A_{\max} = \frac{5\sqrt{10} \times N_{\mathrm{TR}}}{\sqrt{27 K_{\mathrm{total}}}}$ as follows:

$$\alpha_k^{(i)} = \sqrt{A_{\max}^2 - \mathrm{Im}\left\{\left(v_k^{(i)}\right)^* r_k^{(i-1)}\right\}^2} + \mathrm{Re}\left\{\left(v_k^{(i)}\right)^* r_k^{(i-1)}\right\}$$

where $v_k^{(i)} = u^{(i)} \exp\left(-\frac{j2\pi(k - K_C)m^{(i)}}{N_{FFT}}\right)$

5) Find $\alpha^{(i)}$, the largest magnitude of correction allowed without causing any reserved carrier amplitudes to exceed $A_{\max}$:

$$\alpha^{(i)} = \min\left(y^{(i)} - V_{clip}, \min_{k \in S_l} \alpha_k^{(i)}\right)$$

If $\alpha^{(i)} = 0$, then decrease $i$ by 1 and go to step 9.

6) Update the peak reduction signal $c_n^{(i)}$ by subtracting the reference kernel signal, scaled and cyclically shifted by $m^{(i)}$:

$$c_n^{(i)} = c_n^{(i-1)} - \alpha^{(i)} u^{(i)} p_{(n - m^{(i)}) \bmod N_{FFT}}$$

7) Update the frequency domain coefficient for each reserved tone $k \in S_l$:

$$r_k^{(i)} = r_k^{(i-1)} - \alpha^{(i)} v_k^{(i)},$$

Note 2: If only 1 iteration is required, step 7 can be omitted, and steps 4 and 5 reduce to the following:

$$\alpha^{(1)} = \min(y^{(1)} - V_{clip}, A_{\max}).$$

8) If $i$ is less than a maximum allowed number of iterations, increase $i$ by 1 and return to step 2. Otherwise, go to step 9.
9) Terminate the iterations. The transmitted signal, $x'_n$ is obtained by adding the peak reduction signal to the data signal:

$$x'_n = x_n + c_n^{(i)}$$

## M.3 ACE ALGORITHMS

Two types of algorithms for active constellation extension are proposed, the use of which depends upon the constellation dimension and the FEC code rate. The 1-dimensional (1D) constellation algorithm is described in Section M.3.1 and the 2-dimensional (2D) constellation algorithm is described in Section M.3.2. Table M.3.1 indicates the ACE algorithm to be used for each modulation and coding combination.

**Table M.3.1** ACE Algorithm Used for Each Modulation and Code Rate Combination

| Code Rate/ Constellation | 2/ 15 | 3/ 15 | 4/ 15 | 5/ 15 | 6/ 15 | 7/ 15 | 8/ 15 | 9/ 15 | 10/ 15 | 11/ 15 | 12/ 15 | 13/ 15 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **QPSK** | 1D | 1D | 1D | 1D | 1D | 1D | 1D | 1D | 1D | 1D | 1D | 1D |
| **16QAM** | 1D | 2D | 2D | 2D | 2D | 2D | 2D | 2D | 2D | 1D | 1D | 1D |
| **64QAM** | 2D | 2D | 2D | 2D | 2D | 2D | 2D | 2D | 2D | 2D | 2D | 2D |
| **256QAM** | 2D | 2D | 2D | 2D | 2D | 2D | 2D | 2D | 2D | 2D | 2D | 2D |
| **1024QAM** | 1D | 1D | 1D | 1D | 1D | 1D | 1D | 1D | 1D | 1D | 1D | 1D |
| **4096QAM** | 1D | 1D | 1D | 1D | 1D | 1D | 1D | 1D | 1D | 1D | 1D | 1D |

The Active Constellation Extension algorithm produces a time domain signal $x_{ACE}$ that replaces the original time domain signal $x = [x_0, x_1, \ldots, x_{N_{FFT}-1}]$ produced by the IFFT from a set of frequency domain values $X = [X_0, X_1, \ldots, X_{N_{FFT}-1}]$.

### M.3.1 1-D ACE algorithm

The 1-D ACE algorithm is used for the 1-dimensional constellations.

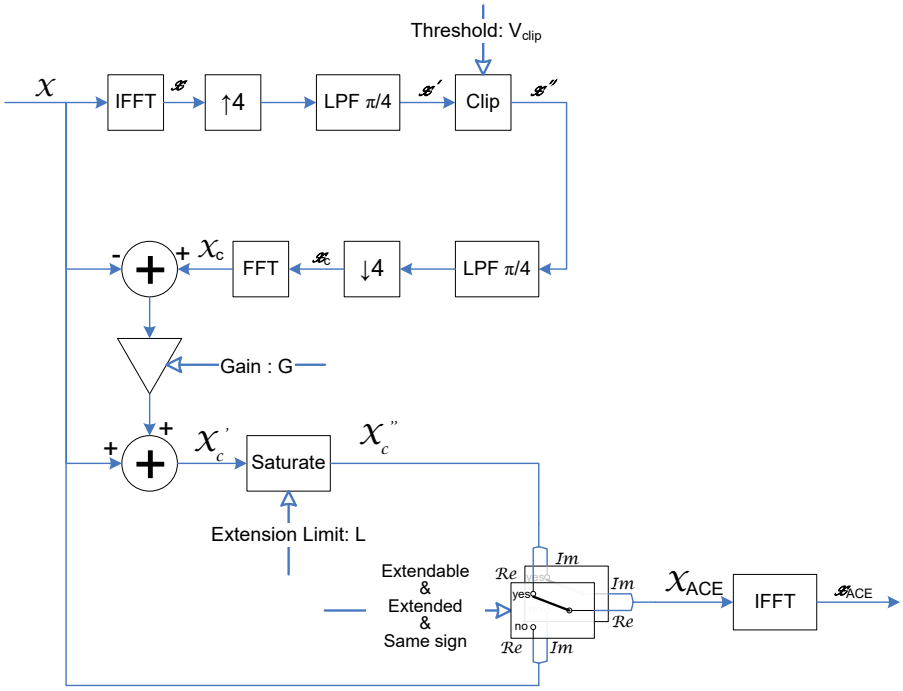


**Figure M.3.1** Implementation example of the ACE algorithm for 1-D constellations.

$x' = [x'_0, x'_1, \ldots, x'_{N_{FFT}-1}]$ is obtained from $x$ through interpolation by a factor of 4.

The combination of IFFT, oversampling and lowpass filtering is implemented using zero padding and a four times oversized IFFT operator.

$x'' = [x''_0, x''_1, \ldots, x''_{N_{FFT}-1}]$ is obtained by applying a clipping operator to $x'$.

The clipping operator is defined as follows:

$$x''_k = \begin{cases} x'_k & , \text{ if } |x'_k| \le V_{clip} \\ V_{clip} \cdot \dfrac{x'_k}{|x'_k|} & , \text{ if } |x'_k| > V_{clip} \end{cases}$$

The clipping threshold $V_{clip}$ is a parameter of the ACE algorithm.

$x_c = [x_{c0}, x_{c1}, \ldots, x_{cN_{FFT}-1}]$ is obtained from $x''$ through decimation by a factor of 4.

The combination of lowpass filtering, downsampling and FFT is implemented using a four times oversized FFT operator.

$X_c$ is obtained from $x_c$ through an FFT operation.

A new signal $X'_c$ is obtained by combining $X_c$ and $X$ as follows:

$$X'_c = X + G \cdot (X_c - X)$$

The extension gain $G$ is a parameter of the ACE algorithm.

$X''_c$ is obtained from $X'_c$ using a saturation operator which operates separately with real and imaginary components, ensuring that individual component magnitude cannot exceed a given value $L$.

$$\mathrm{Re}\{X''_{c,k}\} = \begin{cases} \mathrm{Re}\{X'_{c,k}\}, & \text{if } |\mathrm{Re}\{X'_{c,k}\}| \le L; \\ L, & \text{if } \mathrm{Re}\{X'_{c,k}\} > L; \\ -L, & \text{if } \mathrm{Re}\{X'_{c,k}\} < -L; \end{cases}$$

$$\mathrm{Im}\{X''_{c,k}\} = \begin{cases} \mathrm{Im}\{X'_{c,k}\}, & \text{if } |\mathrm{Im}\{X'_{c,k}\}| \le L; \\ L, & \text{if } \mathrm{Im}\{X'_{c,k}\} > L; \\ -L, & \text{if } \mathrm{Im}\{X'_{c,k}\} < -L; \end{cases}$$

The extension limit $L$ is a parameter of the ACE algorithm.

$X_{ACE}$ is then constructed by simple selection of the real and imaginary components from those of $X$, $X''_c$.

$$\mathrm{Re}\{X_{ACE,k}\} = \begin{cases} \mathrm{Re}\{X''_{c,k}\}, & \begin{array}{c}\text{if } \mathrm{Re}\{X_k\} \text{ is extendable} \\ \text{AND } |\mathrm{Re}\{X''_{c,k}\}| \le |\mathrm{Re}\{X_k\}| \\ \text{AND } \mathrm{Re}\{X''_{c,k}\} \cdot \mathrm{Re}\{X_k\} > 0\end{array} \\ \mathrm{Re}\{X_k\}, & \text{otherwise} \end{cases}$$

$$\mathrm{Im}\{X_{ACE,k}\} = \begin{cases} \mathrm{Im}\{X''_{c,k}\}, & \begin{array}{c}\text{if } \mathrm{Im}\{X_k\} \text{ is extendable} \\ \text{AND } |\mathrm{Im}\{X''_{c,k}\}| \le |\mathrm{Im}\{X_k\}| \\ \text{AND } \mathrm{Im}\{X''_{c,k}\} \cdot \mathrm{Im}\{X_k\} > 0\end{array} \\ \mathrm{Im}\{X_k\}, & \text{otherwise} \end{cases}$$

$x_{ACE}$ is obtained from $X_{ACE}$ through an IFFT operation.

A component is defined as extendable if it is an active cell (i.e. an OFDM cell carrying a constellation point), and if its absolute amplitude is greater than or equal to the maximal component value associated to the modulation constellation used for that cell; a component is also defined as extendable if it is a dummy cell or a null cell in a subframe boundary symbol. As an example, a component belonging to a 1024QAM 9/15 modulated cell is extendable if its absolute amplitude is greater than or equal to 1.4646. (see values *u15* in Table C.1.9)

The value for the gain $G$ is selectable in the range between 1 and 31 in steps of 1.

The clipping threshold $V_{clip}$ is selectable in the range between +0 dB and +12.7 dB in 0.1 dB steps above the standard deviation of the original time-domain signal.

The maximal extension value $L$ is selectable in the range between 0.7 and 2.4 in 0.1 steps.

### M.3.2 2-D ACE Algorithm

The 2-D ACE algorithm is used for the 2-dimensional constellations.

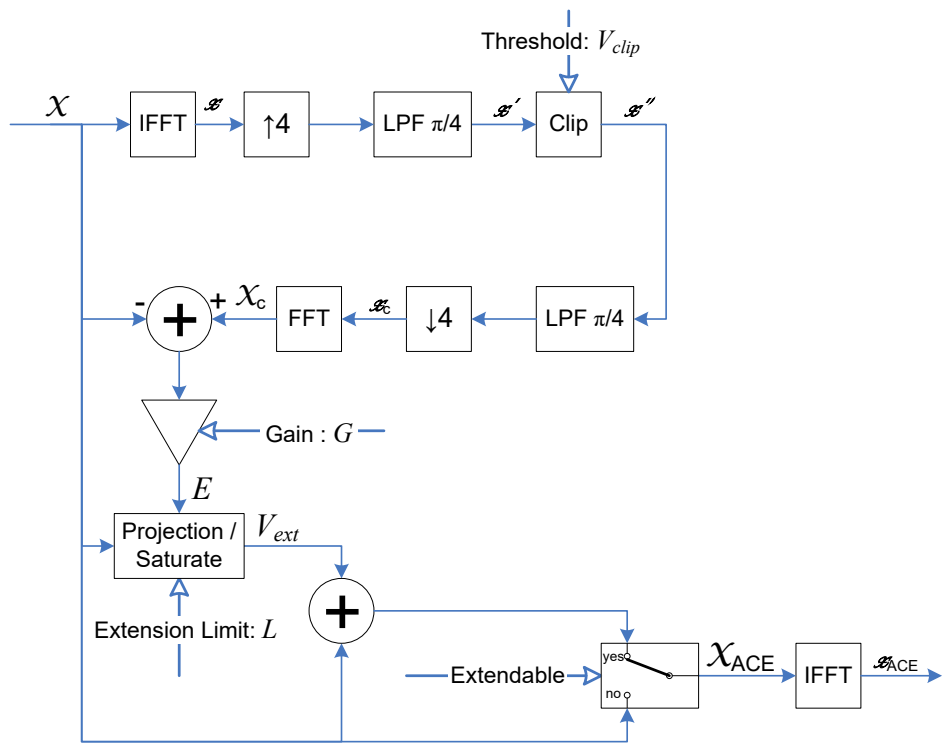


**Figure M.3.2** Implementation example of the ACE algorithm for 2-D constellations.

$x' = [x'_0, x'_1, \ldots, x'_{N_{FFT}-1}]$ is obtained from $x$ through interpolation by a factor of 4.

The combination of IFFT, oversampling and lowpass filtering is implemented using zero padding and a four times oversized IFFT operator.

$x'' = [x''_0, x''_1, \ldots, x''_{N_{FFT}-1}]$ is obtained by applying a clipping operator to $x'$.

The clipping operator is defined as follows:

$$x''_k = \begin{cases} x'_k & , \text{ if } |x'_k| \le V_{clip} \\ V_{clip} \cdot \dfrac{x'_k}{|x'_k|} & , \text{ if } |x'_k| > V_{clip} \end{cases}$$

The clipping threshold $V_{clip}$ is a parameter of the ACE algorithm.

$x_c = [x_{c0}, x_{c1}, \ldots, x_{cN_{FFT}-1}]$ is obtained from $x''$ through decimation by a factor of 4.

The combination of lowpass filtering, downsampling and FFT is implemented using a four times oversized FFT operator.

$X_c$ is obtained from $x_c$ through FFT.

The Error vector $E$ is obtained by combining $X_c$ and $X$ as follows:

$$E = G \cdot (X_c - X)$$

The extension gain $G$ is a parameter of the ACE algorithm.

The Extension vector $V_{ext}$ is obtained as follows:

$$\arg(V_{ext,k}) = \begin{cases} \frac{\theta}{2}, \text{ if } \frac{\theta}{2} < \varphi_{e,k} < 90°; \\ -\frac{\theta}{2}, \text{ if } -90° < \varphi_{e,k} < -\frac{\theta}{2}; \\ \varphi_{e,k}, \text{ otherwise} \end{cases}$$

$$|V_{ext,k}| = \begin{cases} |E_k|, \text{ if } (|E_k| \leq L - |X_k|) \text{ AND } (-90° < \varphi_{e,k} < 90°) \\ L - |X_k|, \text{ if } (|E_k| > L - |X_k|) \text{ AND } (-90° < \varphi_{e,k} < 90°) \\ 0, \text{ otherwise} \end{cases}$$

Where $\varphi_e$ denotes the angle between the argument of reference symbol $X$ and the Error vector $E$. The extension limit $L$ is an input parameter of the ACE algorithm.

The angle θ is an input parameter of the ACE block and is dependent upon the 2-dimensional constellation and code rate. The values of angle θ (in degrees) are given in Table M.3.2.

**Table M.3.2** Values of Angle θ of ACE Algorithm for 2-Dimensional Constellations

| Code Rate/ Cont. | 2/ 15 | 3/ 15 | 4/ 15 | 5/ 15 | 6/ 15 | 7/ 15 | 8/ 15 | 9/ 15 | 10/ 15 | 11/ 15 | 12/ 15 | 13/ 15 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **16QAM** | NA | 33.26° | 35.6° | 38.5° | 44.14° | 44.1° | 44.49° | 44.49° | 42.1° | NA | NA | NA |
| **64QAM** | 22.96° | 39.36° | 41.26° | 19.01° | 21.17° | 22.49° | 22.28° | 22.49° | 22.4° | 19.75° | 18.42° | 16.81° |
| **256QAM** | 36.67° | 40.26° | 19.11° | 22.47° | 8.38° | 11.23° | 11.23° | 10.93° | 11.22° | 10.63° | 8.8° | 8.34° |

$X_{ACE}$ is then constructed by adding the Extension vector $V_{ext}$ to the signal $X$ as follows:

$$X_{ACE,k} = \begin{cases} X_k + V_{ext,k}, \text{ if } X_k \text{ is extendable;} \\ X_k, \text{ otherwise} \end{cases}$$

$x_{ACE}$ is obtained from $X_{ACE}$ through an IFFT operation.

A component $X_k$ is defined as extendable if it is an active cell (i.e. an OFDM cell carrying a constellation point), and if it carries a boundary point of the modulation constellation used for that cell. A component is also defined as extendable if it is a dummy cell or a null cell in a subframe boundary symbol. As an example, a component belonging to a 256QAM 9/15 modulated cell is a boundary point of the constellation if its modulus is greater than or equal to 1.65.

The value for the gain $G$ is selectable in the range between 1 and 31 in steps of 1.

The clipping threshold $V_{clip}$ is selectable in the range between +0 dB and +12.7 dB in 0.1 dB steps above the standard deviation of the original time-domain signal.

The maximal extension value $L$ is selectable in the range between 0.7 and 2.4 in 0.1 steps.

### M.3.3 2-D ACE Constellation Diagrams

The following figures show graphically the 2-dimensional constellation extension using the 2-D ACE algorithm.

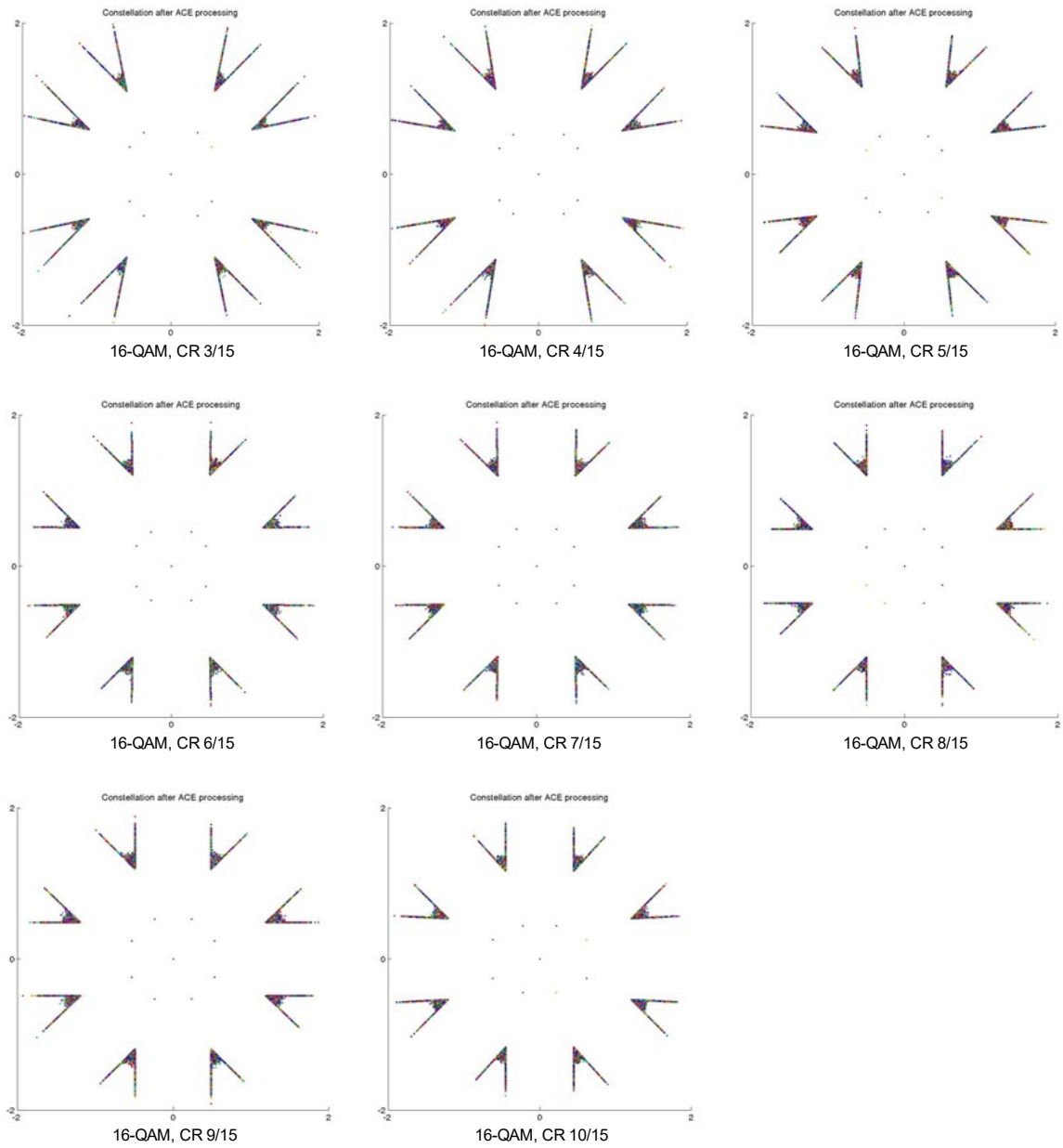


**Figure M.3.3** Constellation diagram for 16QAM when using the defined ACE algorithm.

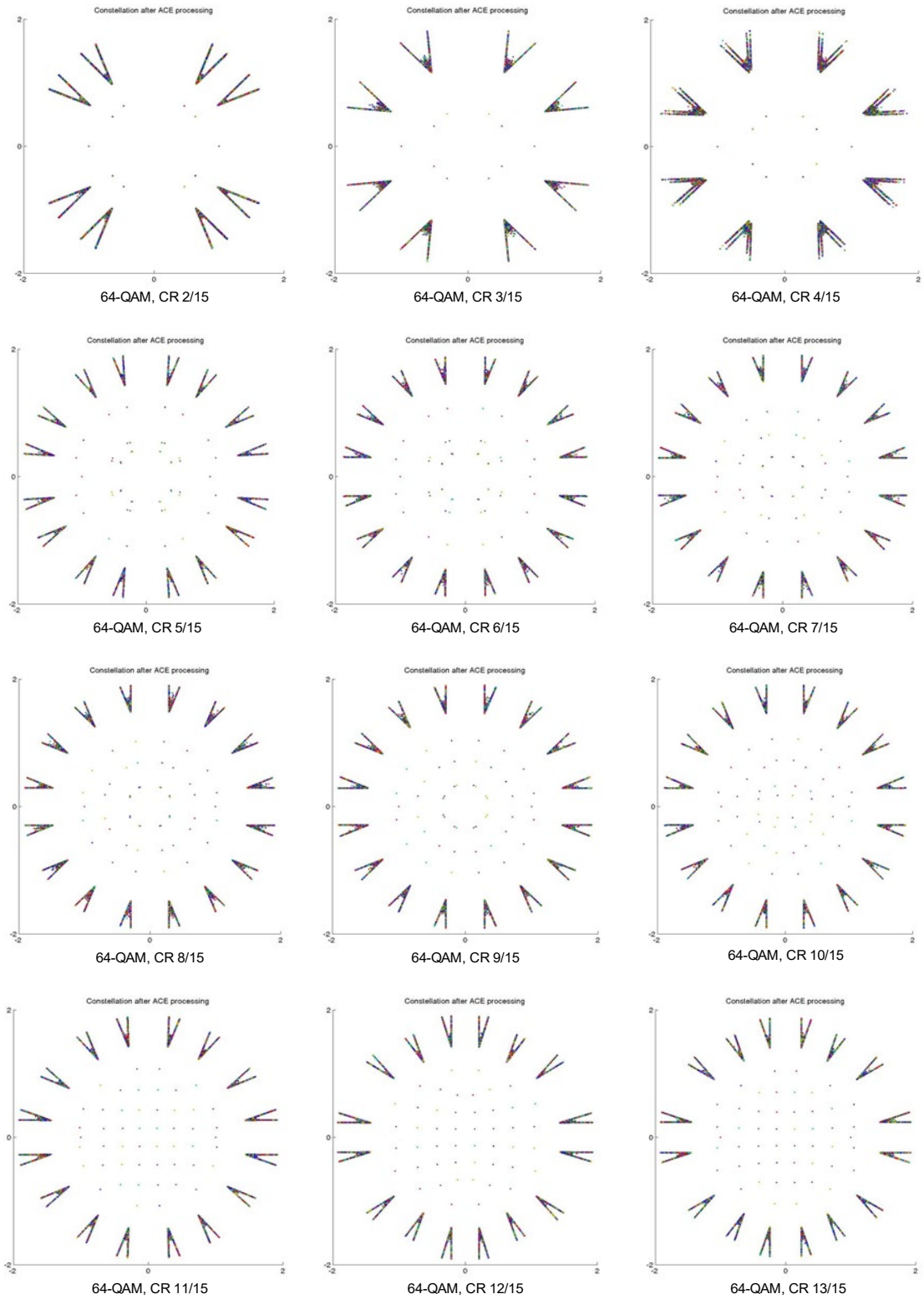


**Figure M.3.4** Constellation diagram for 64QAM when using the defined ACE algorithm.

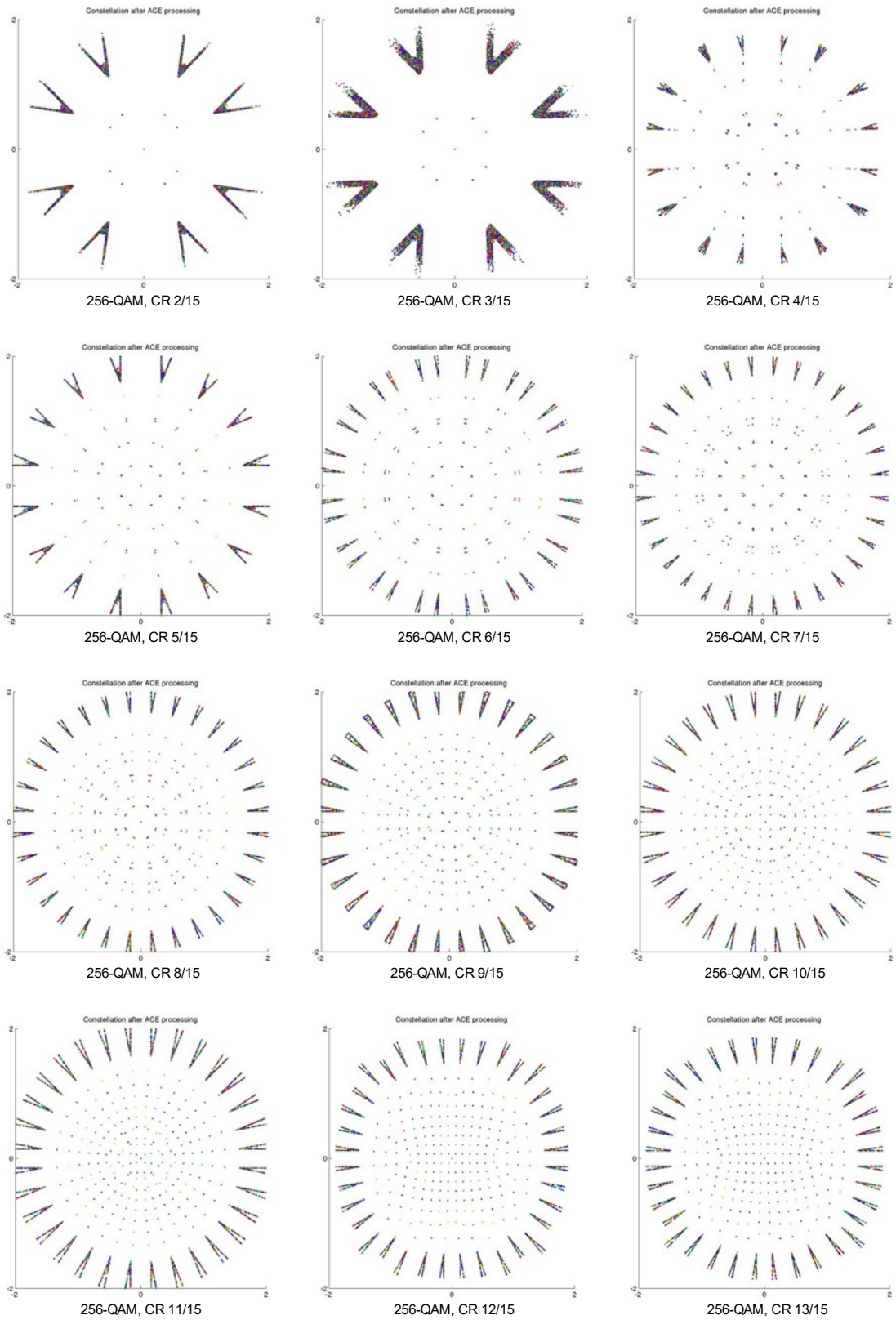


**Figure M.3.5** Constellation diagram for 256QAM when using the defined ACE algorithm.

# *Annex N*: Transmitter Identification (TxID)

## N.1 OVERVIEW

Transmitter identification (TxID) allows uniquely identifying each individual transmitter. Identification is achieved via an RF watermark, which enables system monitoring and measurements, interference source determination, geolocation, and other applications. One of the specific uses of the TxID signal is to allow channel impulse response components of each transmitter to be measured independently to support in-service system adjustments including the power levels and delay offsets of individual transmitters. Such channel impulse response information can be measured by special monitoring instruments but does not need to be processed or otherwise dealt with by ordinary consumer ATSC 3.0 receivers, i.e., the TxID signal appears to such receivers as a small amount of noise in the ATSC 3.0 waveform. TxID is an optional technology but when adopted shall conform to the requirements of this Annex.

Figure N.1.1 depicts the block diagram of the overall transmission system architecture including TxID signal generation. If instructed to do so by signaling from the controlling scheduler, each transmitter in a network will include its TxID in its over-the-air transmission. The TxID signal is a direct sequence buried spread spectrum (DSBSS) RF watermark signal carrying a unique Gold code sequence. Each TxID signal is injected into the host ATSC 3.0 signal in the time domain and is transmitted synchronously with the host ATSC 3.0 signal.

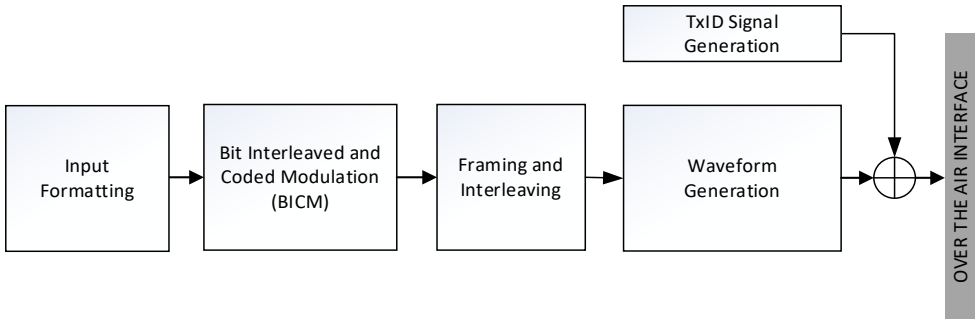


**Figure N.1.1** TxID generation and injection into ATSC 3.0 host signals.

## N.2 CODE GENERATION

The TxID signal carries a Gold code sequence that is unique to each transmitter on a given RF channel within the largest possible geographic region and is transmitted only within the first Preamble symbol period as depicted from Figure N.2.1 to Figure N.2.3**,** where it is added at a reduced level relative to the emissions from the particular transmitter with which it is associated. The code is generated by a pair of shift registers having specified feedback arrangements and set to known values at specified times. The shift registers are clocked at the same baseband sample rate as is used for the host ATSC 3.0 Preamble.

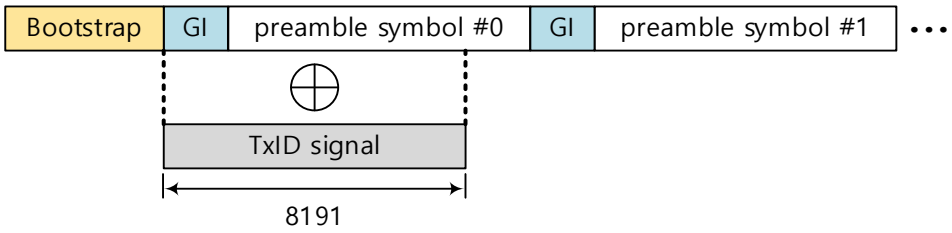


**Figure N.2.1** TxID signal injection into the first Preamble symbol period (8K FFT).

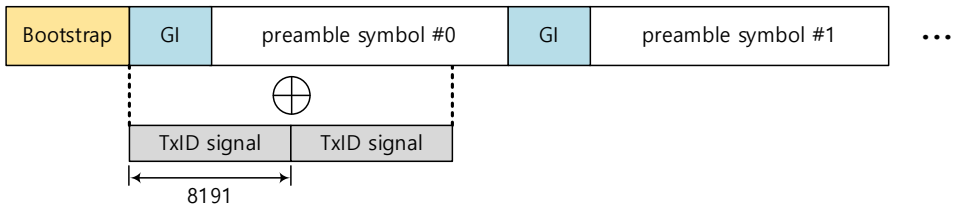


**Figure N.2.2** TxID signal injection into the first Preamble symbol period (16K FFT).

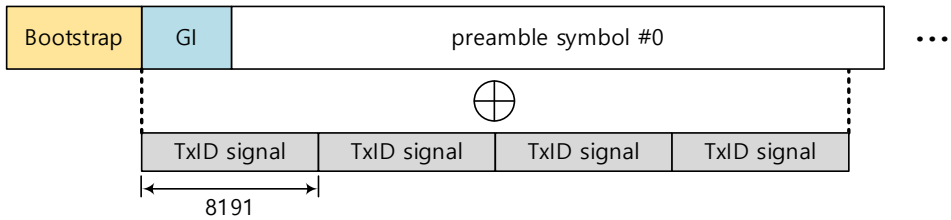


**Figure N.2.3** TxID signal injection into the first Preamble symbol period (32K FFT).

### N.2.1 Multiple Shift Registers

The code transmitted by the TxID signal shall be generated by a pair of shift registers that shall have the lengths, feedback paths, and summing functions defined in Figure N.2.4. The shift registers also shall have inputs through which they can be preloaded during specified setup intervals. The combined output of the shift registers shall be sent to the BPSK modulator described in Section N.3.1 for subsequent injection into and transmission with the ATSC 3.0 host signal.

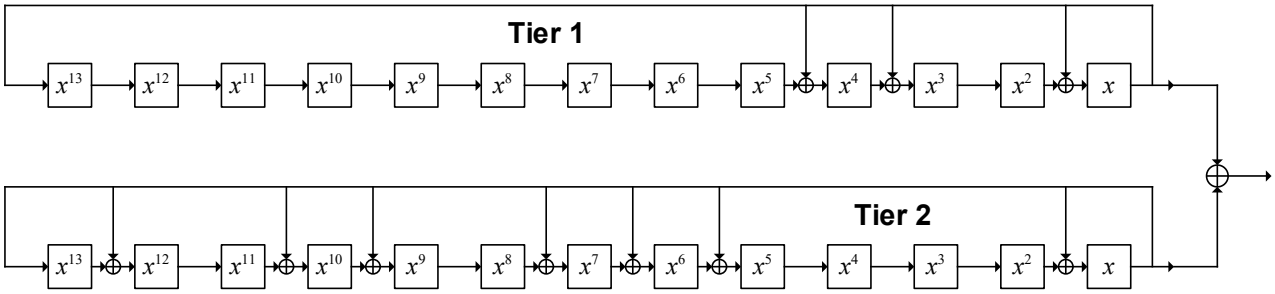


**Figure N.2.4** TxID code generator based on Gold sequence.

The two shift registers shall be defined by the following generator polynomials:

- Tier 1 generator polynomial: $x^{13} + x^4 + x^3 + x + 1$
- Tier 2 generator polynomial: $x^{13} + x^{12} + x^{10} + x^9 + x^7 + x^6 + x^5 + x + 1$

### N.2.2 Clock Rate

The clock applied to the shift registers shown in Figure N.2.4 shall operate at the baseband sample rate of the host ATSC 3.0 payload signal, as defined by the **bsr_coefficient** field of bootstrap symbol 2 [2]. For example, if the signaled value of **bsr_coefficient** were 2, then the baseband sample rate would be 6.912 = (0.384 × (2+16)) MHz.

### N.2.3 Preloaded Values

Each of the two shift registers shown in Figure N.2.4 shall be preloaded prior to the generation of the TxID sequence for each frame. The shift register in Tier 1 of the Gold code sequence generator of Figure N.2.4 shall be preloaded with a value of 1 in the $x$ stage and 0 in all the other stages. A 13-bit **txid_address** shall be preloaded into the $x^{13}$ through $x$ stages of the Tier 2 shift register of the code sequence generator; the MSB shall be preloaded into the $x^{13}$ stage and the LSB into the $x$ stage. A **txid_address** value shall be uniquely assigned to each transmitter on a given RF channel, and that value shall be used by the scheduler for controlling each individual transmitter. The preloading of the shift registers of the code sequence generator shall be as defined in Table N.2.1 In the table, values denoted as $t$ are the respective bits of the **txid_address** field with $t_{12}$ representing the MSB and $t_0$ representing the LSB. According to Table N.2.1 , the TxID sequence has a total length of $2^{13} - 1$ = 8191 bits, and the total number of sequences that can be assigned to individual transmitters is $2^{13}$ = 8192.

**Table N.2.1** Code Sequence Generator Preloading

| | Tier 1 | Tier 2 |
|---|---|---|
| $x^{13}$ | 0 | $t_{12}$ |
| $x^{12}$ | 0 | $t_{11}$ |
| $x^{11}$ | 0 | $t_{10}$ |
| $x^{10}$ | 0 | $t_9$ |
| $x^9$ | 0 | $t_8$ |
| $x^8$ | 0 | $t_7$ |
| $x^7$ | 0 | $t_6$ |
| $x^6$ | 0 | $t_5$ |
| $x^5$ | 0 | $t_4$ |
| $x^4$ | 0 | $t_3$ |
| $x^3$ | 0 | $t_2$ |
| $x^2$ | 0 | $t_1$ |
| $x$ | 1 | $t_0$ |

### N.2.4 Synchronization with Preamble Symbol

The first bit of the TxID pattern shall be output from the shift register arrangement of Figure N.2.4 after the shift registers have been preloaded and after the shift registers have been clocked for the first time after the preloading. This first TxID bit shall be modulated and emitted simultaneously with the first sample of the first Preamble symbol including that symbol's guard interval. The

second TxID bit shall be modulated and emitted simultaneously with the second sample of the first Preamble symbol including that symbol's guard interval, and so on.

When an 8K FFT Preamble symbol is used, the TxID sequence that has a length of 8191 bits shall be emitted once per frame as depicted in Figure N.2.1. When a 16K FFT Preamble symbol is used, the TxID sequence of length 8191 shall be repeated twice within the first Preamble symbol period so that the total length of the TxID sequence shall be 16382 bits as depicted in Figure N.2.2. In this case, the second TxID sequence shall have the opposite polarity to the first TxID sequence in order to average out DC components. When a 32K FFT Preamble symbol is used, the TxID sequence of length 8191 shall be repeated four times within the first Preamble symbol period so that the total length of the TxID sequence shall be 32764 bits as depicted in Figure N.2.3. In this case, the second and fourth TxID sequences shall have the opposite polarities to the first TxID sequence, while the third TxID sequence shall have the same polarity as the first TxID sequence. The FFT size of the Preamble symbols is indicated by the **preamble_structure** parameter of bootstrap symbol 3 as defined in Table H.1.1.

## N.3 CODE TRANSMISSION

### N.3.1 BPSK Modulation

The generated Gold code sequence shall be BPSK modulated before injection into the host ATSC 3.0 Preamble symbol. If the generated sequence bit is 'zero', it shall be modulated as '-1'. If the generated sequence bit is 'one', it shall be modulated as '+1'. The BPSK modulated TxID signal shall be injected into the in-phase part of the host ATSC 3.0 Preamble and shall not be injected into the quadrature part.

### N.3.2 TxID Injection Level

A wide range of injection levels for injecting a TxID signal into the host ATSC 3.0 Preamble is available so that an operator can minimize the performance degradation of the Preamble while maintaining the desired TxID detection performance. The TxID injection level to use, including turning off emission of the TxID signal, shall be provided from the controlling scheduler to transmitter(s).

The TxID injection level shall be defined by the dB values in Table N.3.1 , and the scaled TxID signals shall be injected into the host ATSC 3.0 Preamble immediately following the bootstrap. Note that the dB values are exact, while the linear scaling factors in italics are approximate.

**Table N.3.1** TxID Injection Levels Below Host ATSC 3.0 Preamble

| TxID Injection Level Code | TxID Injection Level Below Preamble (dB) | Scaling Factor (Amplitude) |
|---|---|---|
| 0000 | OFF | *0* |
| 0001 | 45.0 dB | *0.0056234* |
| 0010 | 42.0 dB | *0.0079433* |
| 0011 | 39.0 dB | *0.0112202* |
| 0100 | 36.0 dB | *0.0158489* |
| 0101 | 33.0 dB | *0.0223872* |
| 0110 | 30.0 dB | *0.0316228* |
| 0111 | 27.0 dB | *0.0446684* |
| 1000 | 24.0 dB | *0.0630957* |
| 1001 | 21.0 dB | *0.0891251* |
| 1010 | 18.0 dB | *0.1258925* |
| 1011 | 15.0 dB | *0.1778279* |
| 1100 | 12.0 dB | *0.2511886* |
| 1101 | 9.0 dB | *0.3548134* |
| 1110 | Reserved | - |
| 1111 | Reserved | - |

## N.4 SIGNALING FIELDS

Signaling fields for control of TxID emission are defined within [4]

— End of Document —